FINAL REPORT

EVALUATION OF THE FINAL DATA FOR THE PRICETOWN I UCG FIELD TEST VIA EXISTING THERMODYNAMIC MODELS

By

T. L. Eddy
R. T. Gibbs
C.–M. Jong
T. X. Phouc
W. H. Ford, Jr.

Under

DOE Contract No. DE-AC21-81MC16477

For the Period August 21, 1981 to September 30, 1982

December 1982

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF MECHANICAL ENGINEERING
ATLANTA, GEORGIA 30332

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tions. This led to condensation and solidification of tars in the link and wells. It is imperative to maintain base temperatures by providing superheated steam and oxygen in future field tests, as well as to improve the quality of the product gas.

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NOMENCLATURE

A	area
c_p	constant pressure specific heat or equivalent
C	coefficient to Nusselt No. relation
C_1-C_i	temporary constants defined in text
C1-C5	core wells
CLE	combustion link enhancement
d	diameter (thick seam) or width (thin seam) of cavity
d_{nc}	characteristic length for terminal velocity in natural convection
d_p	pore, grain or pellet diameter
d_z	thickness of devolatilized region when cavity is near virgin coal
D_o	molecular diffusion coefficient of oxygen in air
F	fraction
FG	forward gasification phase
g	acceleration of gravity
Gr	Grashof number
Gz	Graetz number = Pe (d/x)
h	specific enthalpy
h_c, $\bar{h}_c$	heat transfer coefficient (local and average)
h_m	mass transfer coefficient
h_{fg}	enthalpy of vaporization
h_{sf}	enthalpy of fusion
h_{sg}	enthalpy of sublimation or fusion plus vaporization
h_c	enthalpy of combustion

$R_{c/o,2}$	mass ratio of coal consumed to oxygen supplied based on Method II
$R_{ch/o}$	mass ratio of char consumed to oxygen supplied
$R_{vm/o}$	mass ratio of volatile matter consumed to oxygen supplied
Ra	Rayleigh number = Gr Pr
Re	Reynolds number
RCL	reverse combustion linking
Sc	Schmidt number
t	time
T	temperature
T_o	temperature at entrance
u	velocity in x direction
v	velocity in y or r direction
V	volumetric flow rate
Y_{ox}	mass fraction of oxygen in flow
x	axial coordinate, distance from injection well
Y	mass fraction in the coal
z	coal seam thickness

Greek Symbols

α	thermal diffusivity ($k/\rho c_p$)
β_i	eigenvalues for series solutions
γ	mass fraction of water to coal consumed
θ, θ_o	$T-T_w$, T_o-T_w respectively
λ	friction coefficient
μ	dynamic viscosity
ρ	density

s	solid or standard conditions
S	sulfur
SO2	denotes $S + O_2 \rightarrow SO_2$
t	turbulent
T	total
vm	volatile matter
W	water
w	wall
wg	water-gas reaction
∞	refers to virgin coal

Table 1.1. Phases of the Pricetown I field test for computer modeling.

Phase	Starting Date/Time	Julian Date	Stages	Approx. Phase[6]
1 RCL-23	6/9/79 - 12:30	160.520	1	RCL - 1
2 CLE-23	6/15/79 - 10:15	166.430	25	RCL - 2
3 RCL-12	7/9/79 - 14:10	190.590	2	RCL - 3
4 CLE-123A	7/23/79 - 12:30	204.520	13	LE - 1
5 CLE-123B	8/19/79 - 8:00	231.327	11	LE - 2
6 FG	9/23/79 - 14:30	266.590	11	FG
End	10/5/79 - 9:10	278.357	-	-

Table 1.2. Selected time - averaged values for each phase.

Phase	Flow Direction	Rounded Duration (days)	Flow (SCFM) In	Flow (SCFM) Out	Well Pres. (PSIA) Inj	Well Pres. (PSIA) Prod	$\frac{CO}{CO_2}$	$R_{C/H}$	$R_{vm/o}$	$R_{ch/o}$	$R_{c/o,2}$
CL-23	3-2	6.00	35	31	829	108	0.48	3.80	3.93	---	---
LE-23	3-2	7.75	45	56	495	170	0.58	5.61	1.26		
	2-3	16.38	25	42	367	121	0.71	4.73	2.43		
	Phase	24.13	31	46	408	137	0.67	5.01	2.05	---	---
CL-12	1-2	13.88	14	21	773	136	0.38	3.54	1.46	---	---
LE-123A	1-2,3	20.12	29	48	303	151	0.36	5.88	1.41		
	2-1	2.38	14	23	405	178	0.34	5.42	3.74		
	3-1,2	4.25	42	66	228	159	0.77	5.94	1.29		
	Phase	26.75	30	49	300	155	0.42	5.85	1.60	---	---
LE-123B	1-2,3	35.38	182	303	322	55	0.69	4.78	1.62	---	---
	1-2,3	11.75	1203	1982	303	88	1.99	9.71	0.562	0.549	0.789

Table 1.3. Summary of tons of coal consumed and affected, as well as mass consumption efficiency (η_m).

Phase	Volatile Matter			Char	Coal[1]		
	Consumed	Affected	% Consumed	Consumed	Affected	%	η_m
RCL 23	2.46	3.18	77.5	-	8.35	38.1	29.5
CLE 23	14.08	15.40	91.4	0.34	40.43	38.1	35.7
RCL 12	3.40	4.96	72.5	-	12.32	38.1	27.6
CLE 123A	10.96	11.60	94.5	1.00	30.46	38.1	39.3
CLE 123B	111.47	116.01	96.1	0.84	304.65	38.1	36.9
Sub Total	142.37	150.88	94.4	2.18	396.21	38.1	36.5
FG	96.42	101.49	95.0[2]	95.85	266.52	74.0	72.1
TOTAL	238.79	247.30	96.6	98.03	662.73	52.1	50.8

[1] Coal affected is assumed to equal volatile matter affected divided by Y_{vm}.

[2] Assumed value based on linking efficiency.

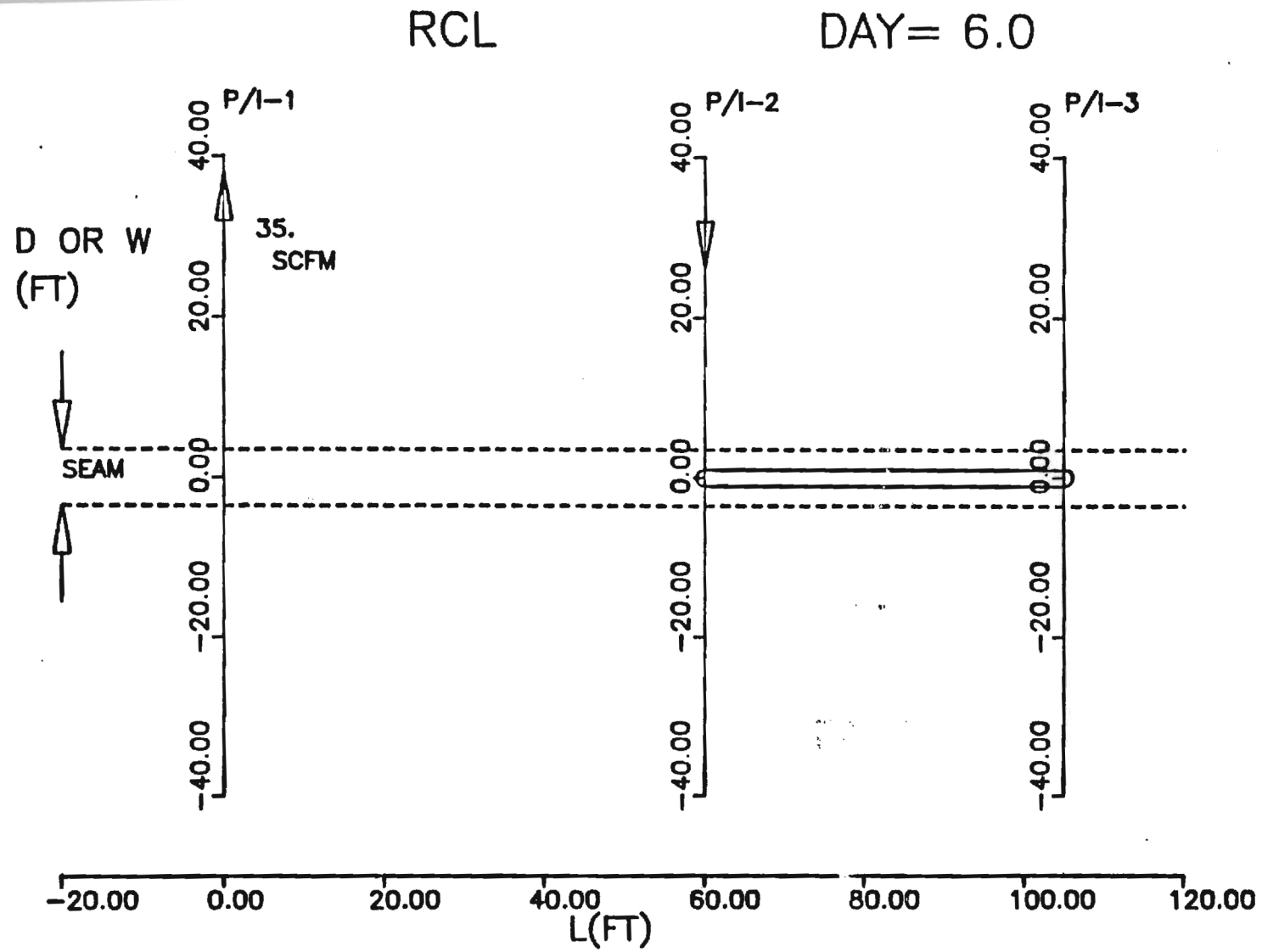


Fig. 1.1: Elevation view of calculated link zone shape after RCL-23.

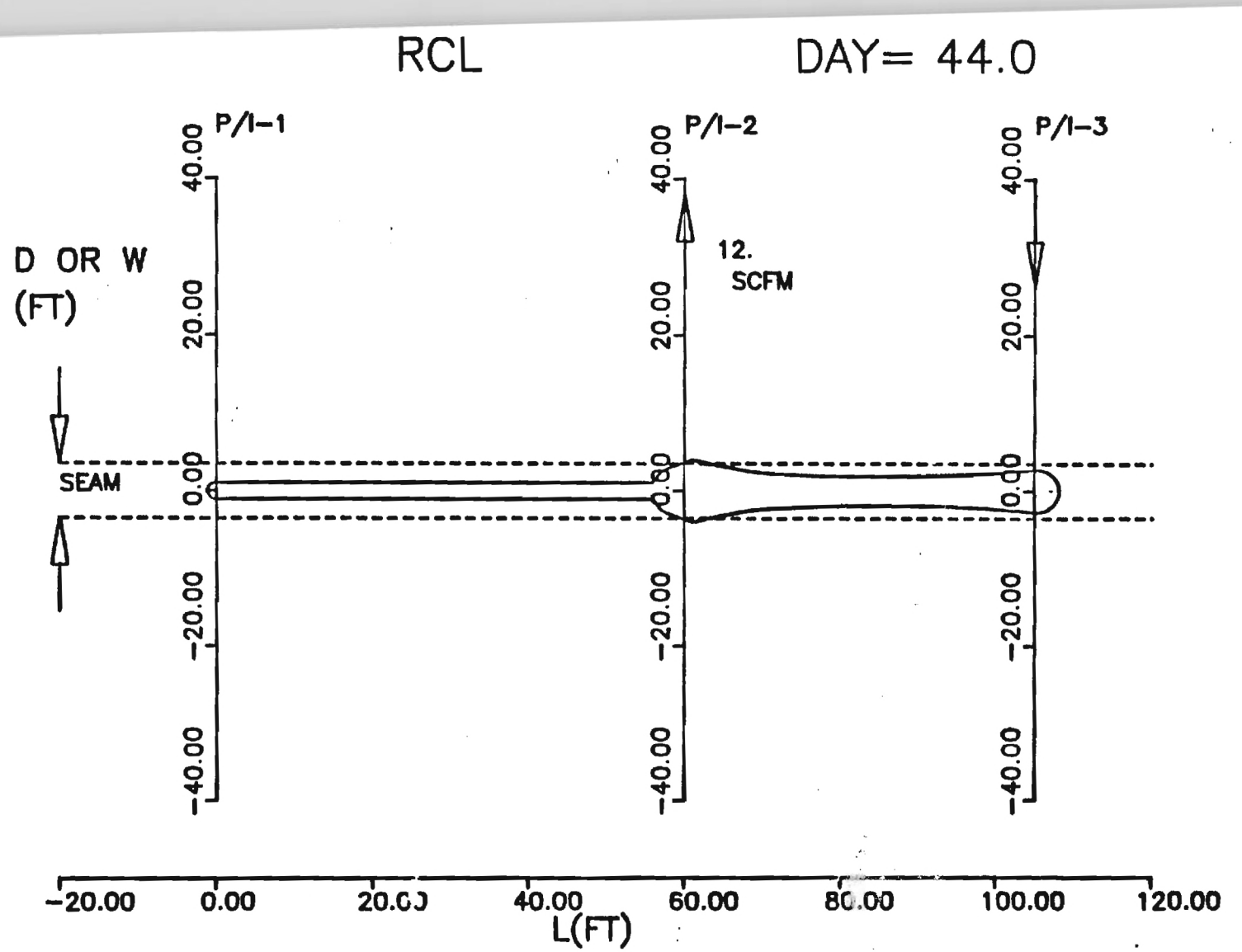


Fig. 1.3: Elevation view of calculated link zone shape after RCL-12.

velocity characteristic length of 0.0123 ft or 28 diameters. The natural convection correlation is again $Nu = 1.67\ Ra^{0.167}$ which indicates a "sub-laminar" flow regime.

The second phase (B) of CLE-123 was constant in flow direction. The intensity averaged about 182 SCFM. The link shape formed prior to gasification should approximate that in Fig. 1.5 as calculated by the CLE computer model. The larger flow rates apparently caused a "laminar" flow regime giving a natural convection correlation of $Nu = 0.15\ Ra^{0.25}$. The porosity remains about 30% but the effective pore diameter doubled to about 0.00080 ft accompanying an increase in the terminal velocity characteristic length to 0.050 ft or about 63 diameters.

The forced convection correlation based on flow through a porous media in an entrance region is included in the CLE computer model but it contributes negligibly to the heat and mass transfer between bulk gas flow and the virgin coal wall in all the CLE phases encountered herein. The "forced" and "natural" convective flows are not coupled mathematically; hence, it appears that the only impact of the increased flow rate (other than providing more total oxygen) is to increase the effective pore size and thus the terminal velocity for the natural convective mechanism. The details of the CLE modeling are discussed in Ch. 3.

.4 Forward Gasification

In the forward gasification (FG) phase, the flow of about 203 SCFM proceeded from P/I-1 to P/I-2 and P/I-3. The large devolatilized link zone around P/I-1 (see Fig. 1.5) and the

apparent shortage of water (as steam) in the reacting zone contributed to a gasification process consisting mainly of the (partial?) oxidation of char and possibly the CO_2-char reduction reaction. This was followed downstream by thermal devolatilization when the hot combustion gases "contacted" the virgin coal as the gases flowed from the cavity through the link to the production well(s). The above hypothesis was validated by the chemical reaction mass balance using the final product gas compositions. Though both the water-gas and water-gas shift reactions were included, the product gas composition indicated that neither reaction was significant over the FG burn; hence $\gamma_R = 0$ here. The major basis for this result is that the methane in the product gas must come from downstream devolatilization. (The temperatures are too high for methanization).

The original calculation for the FG data in Ch. 2, Table 2.4, was based on a coal gasification mass balance in which the coal in question was devolatilized and then gasified. Some char remained, hence the column entitled "fraction of char removed" in Table 2.7. Actually the volatile matter is removed from a different piece of coal than that from which the char is being "gasified." The two processes are uncoupled except that the FG computer model must put them together in the right way to obtain tons removed corresponding to Table 1.3.

At the end of the burn, the forward gasification process had just reached monitoring well M3 and was devolatilizing at M2 as indicated by the thermocouple responses [3]. The FG computer

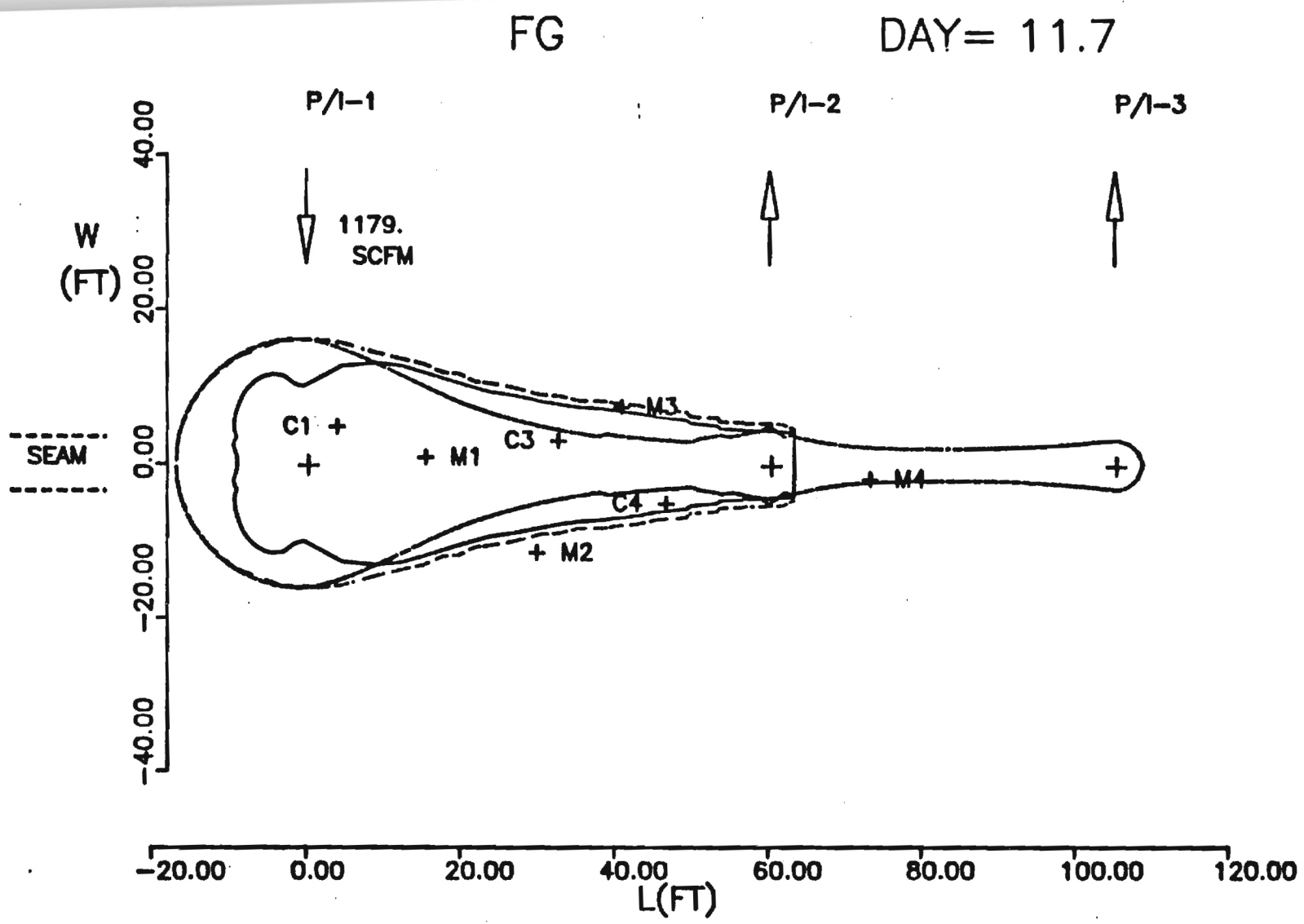


Fig. 1.6: Plan view of computed cavity shape (solid line), predicted char region (long-dashed line), and initial link zone region (short-dashed line) after forward gasification.

suggest that actually a two step process (oxidation of char followed by char - CO_2 reduction) may be more appropriate than the single step (partial oxidation of the char to CO and CO_2) process assumed herein.

In this and the previous model, the temperature drops significantly after four days, when the major portion of the cavity wall area is exposed burden.

The optically thick gas option was run for the same input values. The predicted cavity shape was similar to the former but was larger near the injection well and smaller downstream near M2 and M3 monitoring wells. Predicted wall and gas temperatures given in Figs. 1.10 and 1.11 indicate abnormally high values in the injection region because the radiation is absorbed immediately in the mixed gas region. Note that most of the bulk gas flow is not yet mixed with this region and is therefore not included in the "mixed" bulk gas temperature. Though the optically thick program runs about 10 times faster than the optically thin program, it appears that the optically thin gas assumption gives much better results.

1.5 Conclusion

The present findings are disappointing in that a greater degree of gasification and char removal was not accomplished. The apparent reason is the extent of the link zone prior to gasification which precluded (without a steam-oxygen supply) gasification in the proximity of the virgin coal. This would have provided both moisture and pyrogenic water and additional

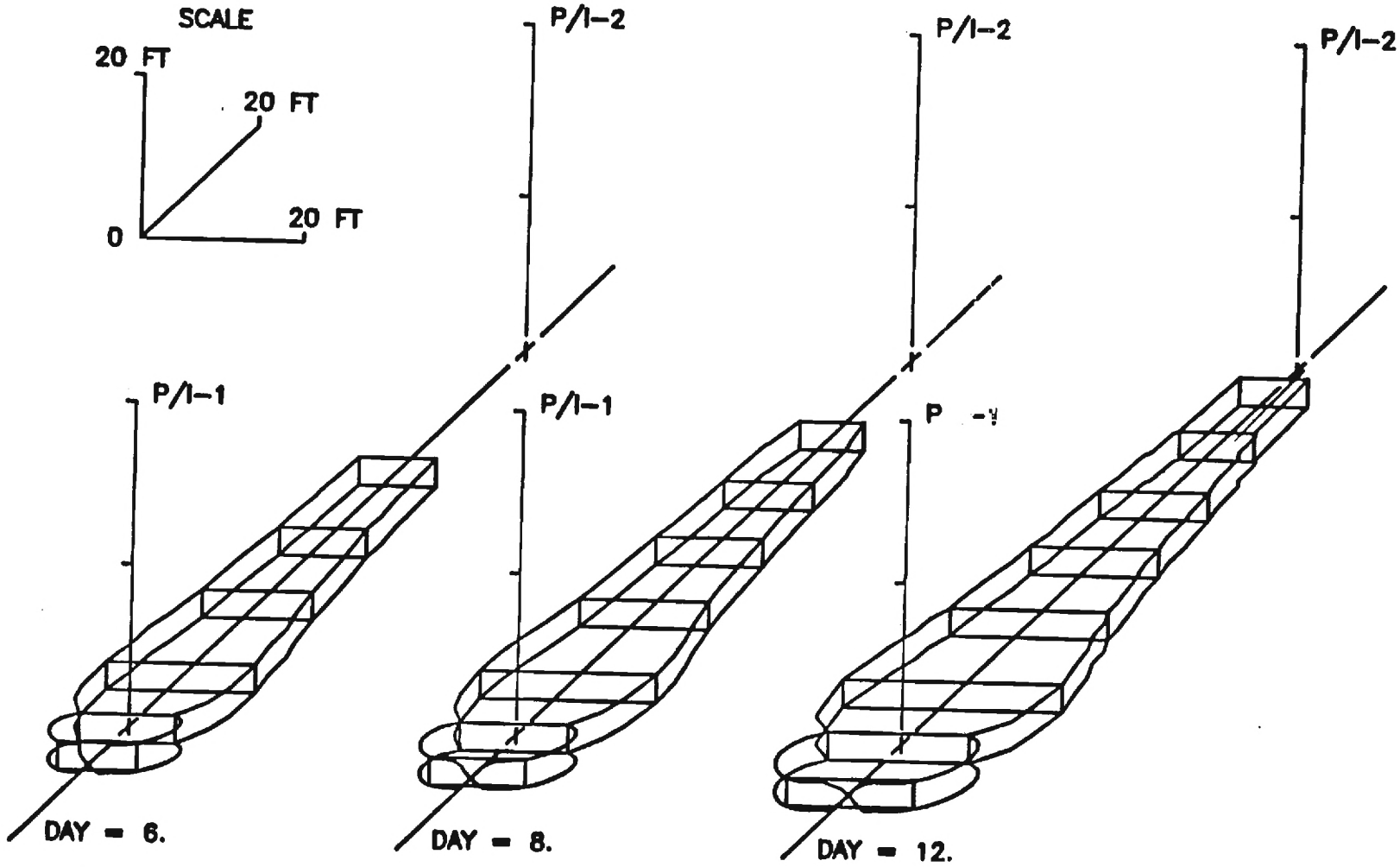


Fig. 1.7: (Cont'd).

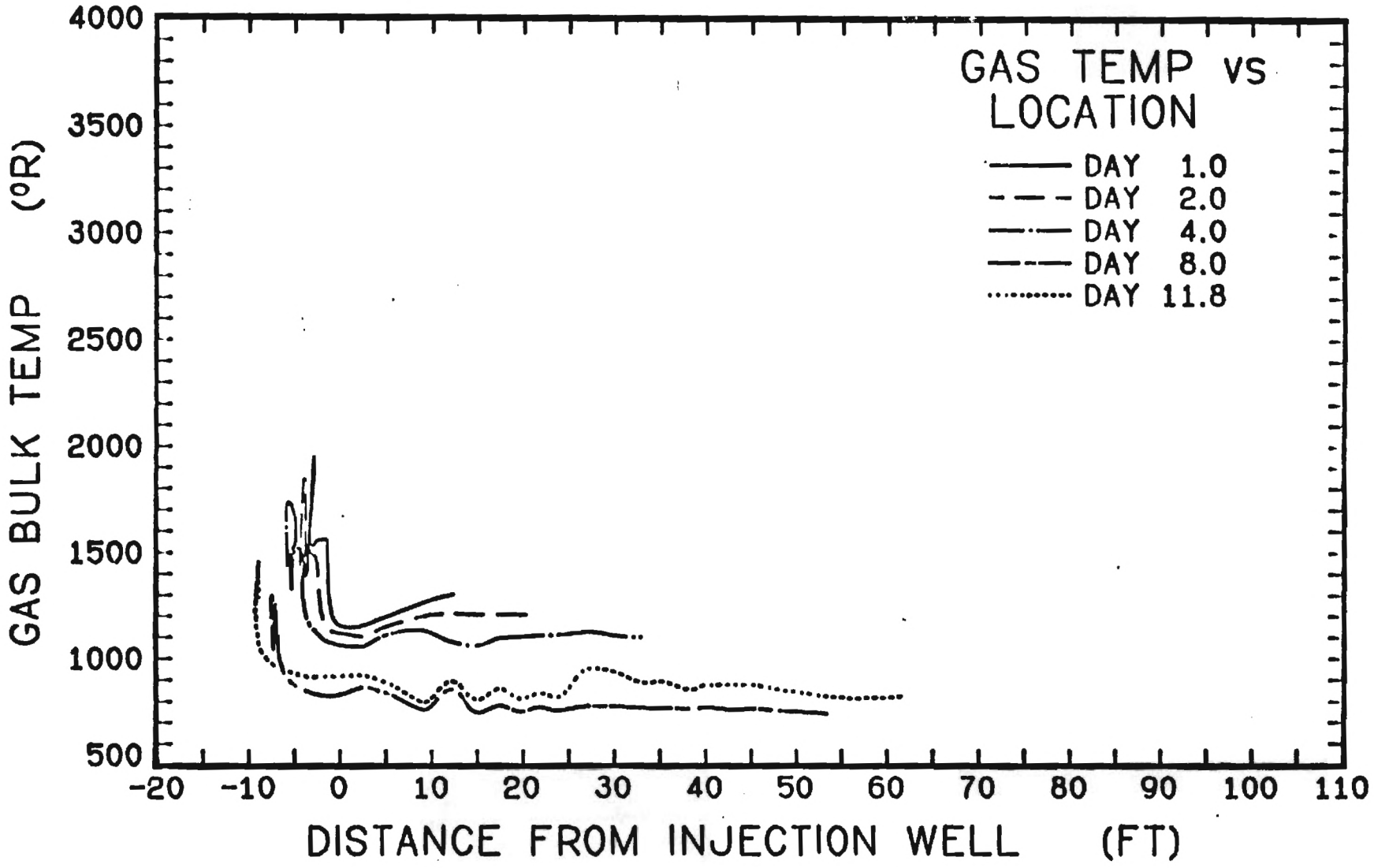


Fig. 1.9: Gas bulk temperatures during forward gasification.

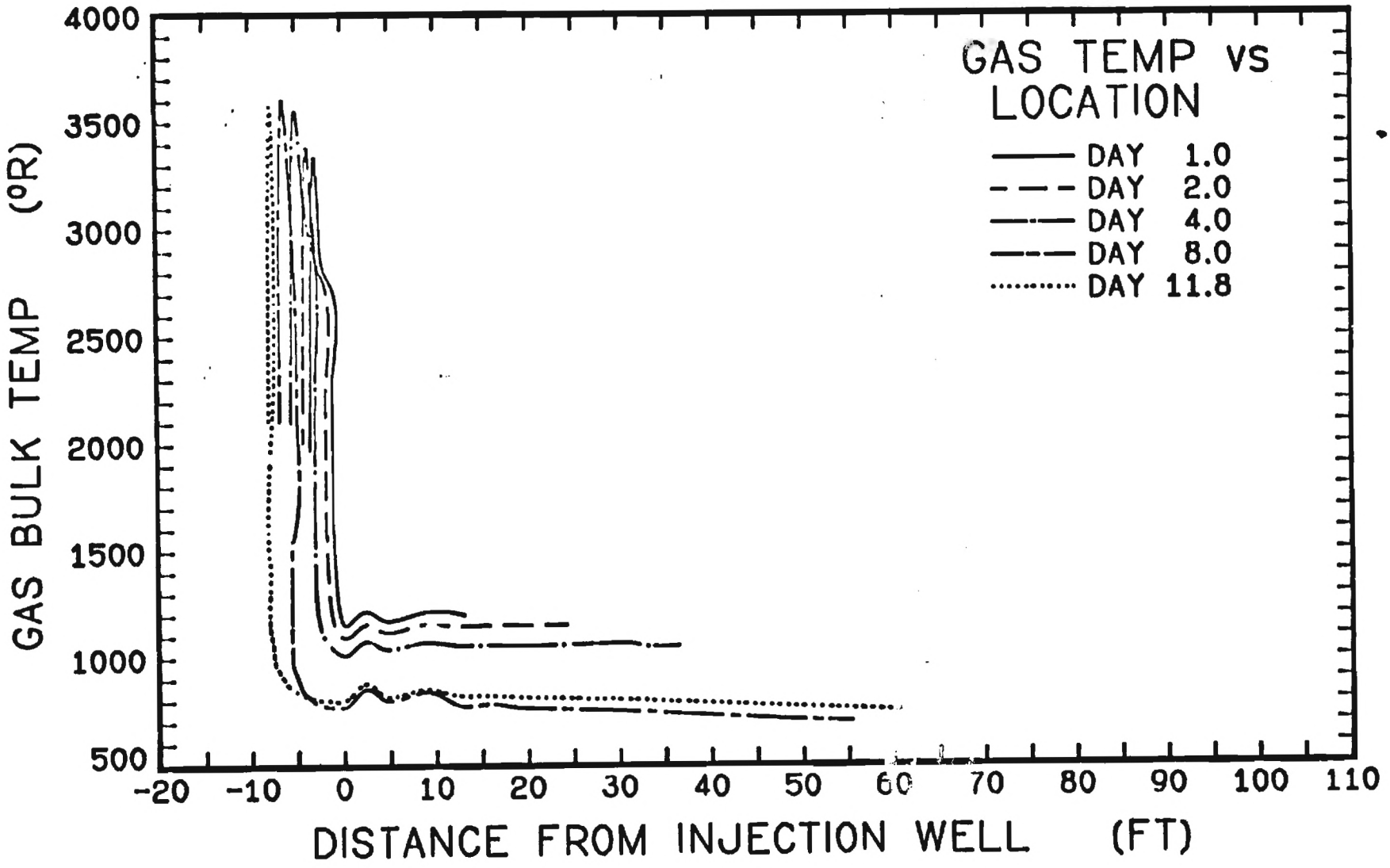


Fig. 1.11: Optically thick model gas bulk temperatures during forward gasification.

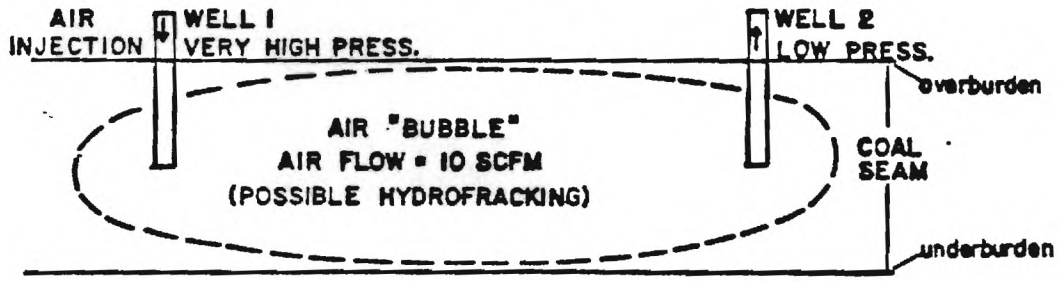
2.0 ANALYSIS OF THE FINAL FIELD TEST DATA

2.1 Introduction

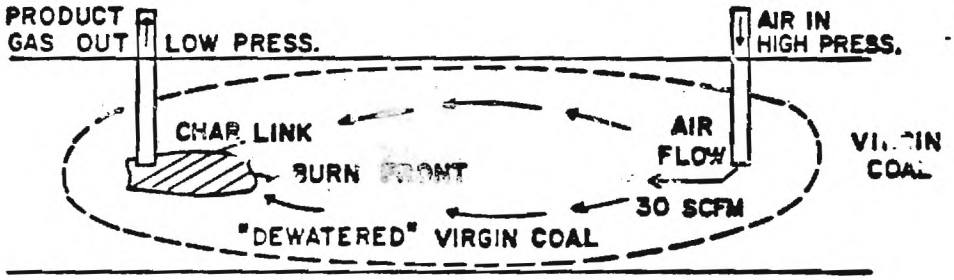
At the Pricetown I field test three vertical production/injection wells (P/I-1, 2 and 3) make up a column of two well pairs along a generally common axis (see Fig. 2.1). Preliminary investigations [3] of the experimented data of the Pricetown I burn suggested the classification of four general process phases for each well pair as illustrated in Fig. 2.2.

1. An air acceptance phase which forms an air bubble by "dewatering" a region between the two wells. Flows are generally very low (about 10 SCFM or 17m^3/hr) and pressure drops high (several tens of atmospheres).
2. An initial linking phase which increases the permeability between wells via reverse combustion linking (RCL) as illustrated in Fig. 2.2, hydrofracking, electrolinking, drilling a borehole, or other means. Flow rates may double or triple and pressure drops decrease, but not proportionately. Once started, the RCL illustrated is usually completed without interruption. "Reverse" indicates the burn front moves opposite to the flow direction, which enhances the increased product gas flow rate and oil and tar removal.
3. A link enhancement phase usually occurs next because the flow rates are not yet adequate to support combustion of

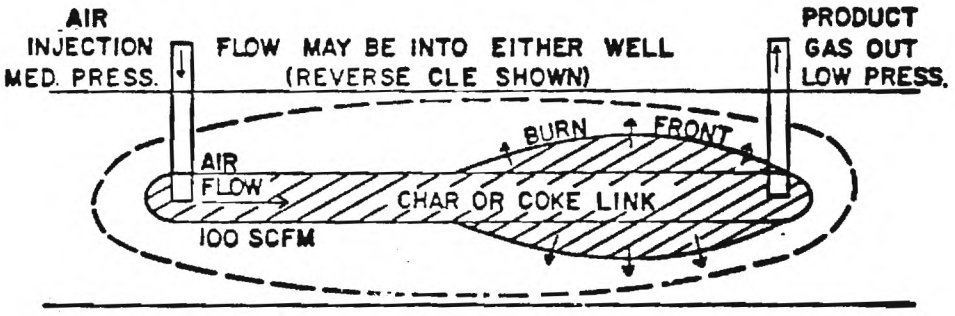
) AIR ACCEPTANCE PREPARATION PHASE:



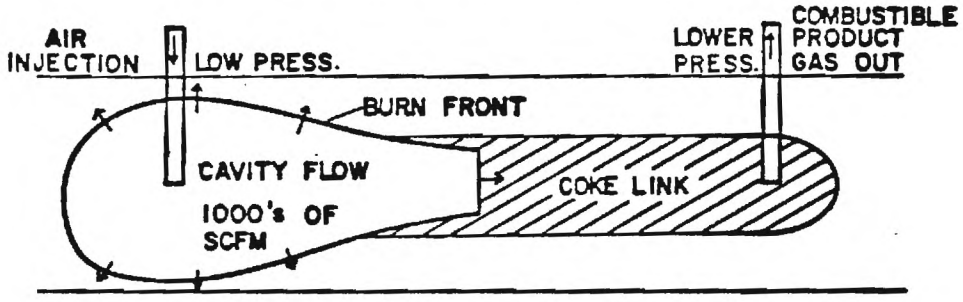
) INITIAL LINKING PHASE: REVERSE COMBUSTION LINKING (RCL)



LINK ENHANCEMENT PHASE: COMBUSTION LINKING ENHANCEMENT (CLE)



GASIFICATION PHASE: FORWARD GASIFICATION (FG)



2.2: General UCG process phases using the linked vertical well geometry.

where

x = average value of interest for one stage duration.

x_{hrpt} = hourly reported value.

Δt = time interval (equal to 1 hr.).

$\sum \Delta t$ = duration of a stage.

When data was missing the mean value between the last preceeding and the first following data values was used. The duration of a stage is limited by changes in flow direction or significant changes in pressure or gas composition.

The present chapter averages data and calculates relevant parameter valves over the appropriate RCL, CLE and FG phases for the appropriate well pairs as indicated in Table 1.1. In some cases, two wells were used for production, and hence more than two wells may be indicated. For the tables in Ch. 2, the first well indicated under "direction" is the single injection well.

2.3 Chemical Reaction Equation

The general chemical reaction equation is assumed to be

$$a(C_xH_yO_zS_v)_{coal} + b(O_2 + 3.719N_2 + 0.043\ Ar) + cH_2O \rightarrow$$

$$dCO + eCO_2 + fCH_4 + g_TH_2O + h_1H_2S + h_2S + iH_2$$

$$+ jN_2 + kO_2 + nAr + \ell C_{ch} + m(C_wH_yO_zS_v)_{vm}. \qquad (2.2)$$

Table 2.1: Ultimate and Proximate Analysis of Pricetown I Coal [8]

Component	Ultimate	Proximate
C	0.7206	
H	0.0482	
O_x	0.05235	
S	0.04292	
Ash (incl. N)	0.1215	0.1215
Moisture	0.01362	0.01362
Vol. Matter		0.3808
Fixed Carbon		0.4841

Table 2.2: Molar Fractions for Molecular Weights

Species	Y_i	M_i	X_i(1 lb/mole) Y_i/M_i	$\frac{Y_i}{M_i} / \sum \frac{Y_i}{M_i}$	X_i (MAF) Normalizing to Carbon	Var.
C	0.7206	12	0.06005	0.53206	1.000	=x
H	0.0482	1	0.04820	0.42707	0.803	=y
Ox	0.05235	16	0.00327	0.02897	0.0545	=z
S	0.04292	32	0.00134	0.01187	0.0223	=v
		Totals	0.11286	0.99997		
C_{vm}	0.2362	12	0.01968	0.1744	0.3278	=w
C_{FC}	0.4841	12	0.04037	0.3577	0.6722	=u

$$b = j/3.719 \ . \qquad (2.6)$$

Substituting this value for b into the carbon, hydrogen and oxygen species balances where appropriate gives three equations with four unknowns.

$$xa - wm + 0 - \ell = d + e + f \equiv C_1 \ , \qquad (2.7)$$

$$ya - y\,m + 2c_g + 0 = 4f + 2h_1 + 2i \equiv C_2 \ , \qquad (2.8)$$

$$za - zm + c_g + 0 = d + 2e + 2k - 2j/3.719 \equiv C_3 \ . \qquad (2.9)$$

where the rhs of each equation is a constant for a given stage.

Separate solutions can be obtained for linking and gasification via the probable assumptions that during linking no char is removed (ℓ = const = a {x-w}) or that during gasification all the volatile matter is consumed (m = o). This was the initial approach here. The assumption appears to be valid for the linking. In this application the gasification assumption was found to be invalid because of the extensive link zone geometry prior to gasification later. Others [6] have obtained a solution assuming more detailed carbonization assays which are beyond the scope of this work.

It is apparent from (2.12) that only the difference a-m can be determined and not the a or m values.

The a and m values are obtained using the experimental carbon to hydrogen mass ratio $R_{C/H}$. If all the volatile matter is consumed $R_{C/H}$ is about 5, if all the coal is consumed $R_{C/H}$ is about 15, and if only char is consumed the value should approach infinity. It is assumed that the volatile matter removed is proportional to the experimental $R_{C/H}$ value. The actual or experimental carbon consumed per hydrogen consumed value is corrected for the net water reacting using (2.14):

$$R_{C/H} = \frac{(d + e + f)M_C}{(4f + 2h_1 + 2i - 2c_g)M_H} = \frac{12C_1}{(C_2 - 2c_g)}. \qquad (2.15)$$

The available $R_{C/H}$ for volatile matter only is

$$R_{C/H}\Big|_{vm,avail} = w\, M_C/(yM_H) = 12\, w/y. \qquad (2.16)$$

The fraction of volatile matter consumed is

$$F_{vm,cons} = \frac{R_{C/H}y}{12w} \qquad (2.17)$$

and the fraction reamining is

$$\frac{m}{a} = 1\text{-}F_{vm,cons} = 1 - \frac{R_{C/H}y}{12w}. \qquad (2.18)$$

2.6 Relations for Gasification: Method I

Under the assumption that all of the volatile matter is oxidized and/or reduced first

$$m = 0, \tag{2.24}$$

and equations (2.7) to (2.9) become

$$\begin{aligned} ax - \ell &= C_1, \\ ay + 2c_g &= C_2, \\ az + c_g &= C_3. \end{aligned} \tag{2.25}$$

Solving for a, c_g and ℓ gives

$$a = (C_2 - 2C_3)/(y - 2z), \tag{2.26}$$

$$c_g = C_3 - za, \tag{2.27}$$

$$\ell = xa - C_1. \tag{2.28}$$

Then the coal <u>affected</u> per oxygen consumed is

$$R_{c/o}\Big|_{aff} = \frac{aM_{coal}}{bM_{O2}} = \frac{axM_C/Y_C}{bM_{O2}} = \frac{1.395\ ax}{jY_C}, \tag{2.29}$$

where either term can be used equivalently. The "coal" <u>consumed</u> per oxygen consumed is

$$R_{c/o,1} = \frac{a\ M_{coal} - \ell\ M_{char}}{b\ M_{O2}} = \frac{(ax - \ell)\ M_C/Y_C}{b\ M_{O2}}$$

$$= 1.395\ C_1/(jY_C). \tag{2.30}$$

2.7 Relations for Gasification: Method II

The total averages of the linking data (Table 1.3) shows that 95% or more of the link zone has been devolatilized. Our CLE computer model (Fig. 1.5) shows that the volatile matter in the virgin coal is about 15 feet or more away from the injection well. Total coal "gasification" is therefore improbable over much of the burn. This section presents the relations to be utilized assuming local gasification of char followed by downstream devolatilization via heat transfer from the hot product gas. The forward gasification computer program selects either method depending upon the proximity of the virgin coal well.

Initially we assumed that the gasification process included full or partial oxidation of the char plus the $C + CO_2 \rightarrow 2CO$ and $C + H_2O \rightarrow CO + H_2$ reduction reactions, as well as the water-gas shift reaction $CO + H_2O \rightarrow CO_2 + H_2$. There are a sufficient number of equations that the unknown coefficients can be calculated explicitly if it is assumed that the methane comes from the volatile matter. The temperatures measured appear to be too high to allow methanization and if the methane comes from outgassing the result is less conservative than the present assumption as well as being a suddenly large and essentially constant level of outgassing.

The calculations produced a significant negative amount of water reacting in the water gas shift reaction which means we produced water and CO from CO_2 and H_2, an unlikely result.

Assumptions:

No water-gas reaction

No water-gas shift reaction

Volatile matter → CH_4, CO, H_2, C_2

Oxidation of char to CO, CO_2

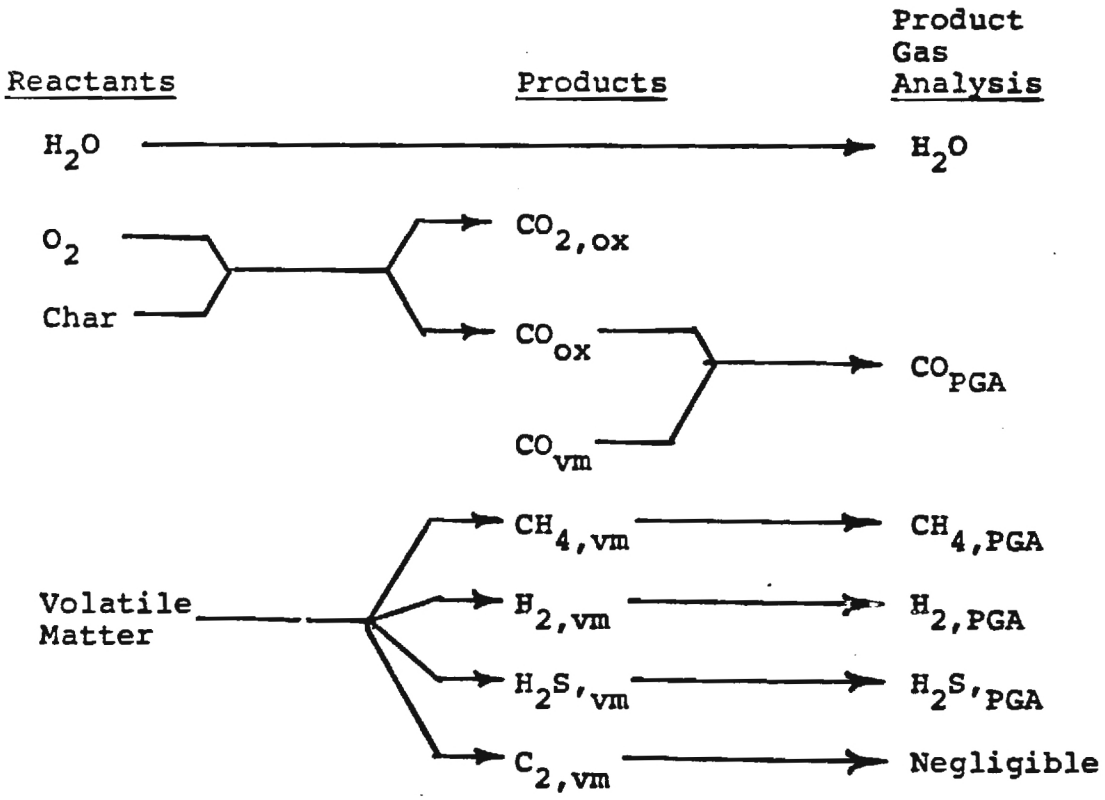


Figure 2.3: Scheme for Probable Gasification Reactions.

measurements was equivalent to about 3.5% of the wet PGA [3] or about 3.5 moles/100 moles of dry PGA. Comparing with about 40 MAF moles of coal this would correspond to a γ_R of 0.11. This value is slightly larger than that due to the moisture and pyrogenic water that could be formed from oxidation of the volatile matter hydrogen.

In summary the amount of water apparently available is insignificant, which gives further evidence to the lack of any significant gasification processes occuring over the burn. Just partial oxidation of the char locally and thermal devolatilization downstream apparently occurred.

When the gasification reaction comes to within a certain distance from the virgin coal wall, it is assumed that volatile matter in the virgin coal and fixed carbon in the char are removed in proportion to their respective concentrations in coal. The previous value of $R_{c/o,1}$ gave coal consumed based on averaged carbon consumed. This must be corrected to reflect total coal removal when the reaction is in the proximity of the virgin coal wall. For this work, the value is determined from the field test values via $F_{ch,R}$ in Table 2.7 as

$$R_{c/o,2} = R_{c/o,1} \Big/ \left(1 + \left[\frac{Y_c - Y_{FC}}{Y_c}\right]\left[\frac{1-F_{ch,R}}{F_{ch,R}}\right]\right) , \qquad (2.49)$$

where $R_{c/o,2}$ is then the equivalent average of coal consumed to oxygen consumed when it is assumed that some of the volatile

$$M_{coal} = 1 = \Sigma\, x_i\, M_i$$

$$M_{combustibles} = M(C_w\, H_y\, O_z\, S_v) = xM_C + yM_H + zM_{ox} + vM_S$$

$$= Y_C + Y_H + Y_{ox} + Y_S = 0.8640 \qquad (2.35)$$

$$M_{vm} = M(C_w H_y O_z S_v) = Y_{C,vm} + Y_H + Y_{ox} + Y_S = 0.3796$$

$$M_{char} = M(C_{x-w}) = Y_{C,FC} = 0.4841 \ .$$

The present computer program calculates values using these molecular weights, then converts to MAF values.

The MAF values are calculated as shown in Table 2.2. The molecular weights are :

$$M_{coal,MAF} = \Sigma\, x_i\, M_i = 1(12) + 0.803(1) + 0.0545(16) + 0.0223(32)$$

$$= 14.39$$

$$M_{vm,MAF} = 0.3278(12) + 0.803(1) + 0.0545(16) + 0.0223(32)$$

$$= 6.32 \qquad (2.36)$$

$$M_{char,MAF} = 0.6722(12) = 8.07$$

Table 2.3: Averaged final data for RCL-23 at Pricetown I.

PHASE 1 REVERSE COMBUSTION LINKING 23 AT PRICETOWN I

STAGE	INITIAL JD	INITIAL DURATION	ROUNDED JD	ROUNDED DURATION	TIME (HRS)	FLOW DIRECTION	SCFM IN	SCFM OUT	P/I-1	P/I-2 (PSIA)	P/I-3
1	160.520	5.900	160.500	6.000	12.30	32	35.38	31.0	449.0	108.0	829.0

STAGE	ROUNDED JD	ROUNDED DURATION	H2	N2	CH4	CO	O2	H2S	AR	CO2
1	160.500	6.000	8.22	60.74	12.75	5.10	.44	1.30	.77	10.68

STAGE	ROUNDED JD	ROUNDED DURATION	COAL AFFECTED	NET H2O REACT	VOLATILE REACT	PER CENT AIR LOST	PER CENT VOLATILE REMOVED	R(VM/O)	CO/CO2	R(C/H)
1	160.500	6.000	112.35	-10.068	25.29	31.9	77.488	1.056	.478	3.797

Table 2.4: Averaged final data for CLE-23 at Pricetown I.

STAGE	INITIAL JD	INITIAL DURATION	ROUNDED JD	ROUNDED DURATION	TIME (HRS)	FLOW DIRECTION	SCFM IN	SCFM OUT	P/I-1	P/I-2 (PSIA)	P/I-3
1	166.430	.177	166.500	.125	10.15	23	51.17	62.21	487.0	499.0	212.0
2	166.607	.170	166.625	.250	14.30	23	51.40	109.90	482.0	498.0	214.0
3	166.777	.590	166.875	.500	16.35	32	42.14	85.70	466.0	130.0	316.0
4	167.367	.167	167.375	.250	8.45	23	31.91	28.43	453.0	503.0	159.0
5	167.534	.135	167.625	.125	12.45	32	49.50	32.74	448.0	192.0	408.0
6	167.669	.111	167.750	.125	16.00	23	37.48	20.88	444.0	395.0	210.0
7	167.780	.600	167.875	.625	18.40	32	41.17	38.56	431.0	134.0	380.0
8	168.380	.212	168.500	.125	9.05	23	36.10	15.32	419.0	574.0	195.0
9	168.592	.139	168.625	.125	14.10	32	53.21	44.14	414.0	164.0	441.0
10	168.731	.608	168.750	.625	17.30	32	54.70	74.20	403.0	116.0	476.0
11	169.339	1.142	169.375	1.125	8.05	32	52.71	65.63	377.0	160.0	611.0
12	170.481	1.066	170.500	1.125	11.30	32	56.83	63.76	491.0	220.0	624.0
13	171.547	.427	171.625	.375	13.05	23	18.46	23.80	483.0	818.0	193.0
14	171.974	1.434	172.000	1.500	23.20	32	45.02	42.11	462.0	177.0	602.0
15	173.408	.163	173.500	.125	9.45	32	37.19	30.96	621.0	193.0	569.0
16	173.571	.638	173.625	.625	13.40	23	11.46	20.76	690.0	775.0	193.0
17	174.209	1.125	174.250	1.125	5.00	32	31.55	48.84	640.0	186.0	412.0
18	175.334	.615	175.375	.625	8.00	23	11.06	12.34	623.0	677.0	176.0
19	175.949	.507	176.000	.500	22.45	32	35.46	53.55	609.0	191.0	339.0
20	176.456	.119	176.500	.125	10.55	23	25.42	20.28	608.0	529.0	184.0
21	176.575	.974	176.625	1.000	13.47	23	26.16	46.98	576.0	259.0	105.0
22	177.549	3.882	177.625	3.875	13.10	23	28.06	47.01	462.0	278.0	113.0
23	181.431	7.986	181.500	8.000	10.20	23	22.65	43.67	408.0	342.0	105.0
24	189.417	.271	189.500	.250	10.00	32	31.47	70.77	345.0	134.0	153.0
25	189.688	.902	189.750	.875	16.30	23	30.05	40.10	335.0	293.0	112.0

Table 2.4: (Cont'd)

STAGE	ROUNDED JU	ROUNDED DURATION	COAL AFFECTED	NET H2O REACT	VOLATILE REACT	AIR LOST PER CENT	PER CENT VOLATILE REMOVED	R(VM/O)	CO/CO2	R(C/H)
1	166.500	.125	119.75	7.941	26.56	37.1	77.819	1.700	.560	3.813
2	166.625	.250	29.48	-1.140	-3.54	-89.1	112.004	0.352	1.919	5.488
3	166.875	.500	103.79	-2.383	4.07	-34.8	96.078	1.420	1.061	4.707
4	167.375	.250	96.84	3.535	3.32	42.8	96.574	1.374	.761	4.732
5	167.625	.125	96.84	3.535	3.32	57.5	96.574	1.374	.761	4.732
6	167.750	.125	96.84	3.535	3.32	53.9	96.574	1.374	.761	4.732
7	167.875	.625	96.84	3.535	3.32	39.9	96.574	1.374	.761	4.732
8	168.500	.125	96.84	3.535	3.32	72.7	96.574	1.374	.761	4.732
9	168.625	.125	62.60	.365	-16.55	35.7	126.431	0.964	.485	6.195
10	168.750	.625	85.84	-6.070	- 4.54	- 2.4	105.289	1.131	1.142	5.159
11	169.375	1.125	126.18	-2.001	10.96	19.7	95.311	1.685	.550	4.474
12	170.500	1.125	132.15	1.363	5.25	31.6	96.029	1.966	.363	4.705
13	171.625	.375	177.67	28.965	- 9.16	81.8	305.196	12.517	.247	5.152
14	172.000	1.500	64.12	-5.878	-17.35	22.8	127.058	0.932	.678	6.225
15	173.500	.125	76.08	-2.918	-13.48	36.1	117.720	1.100	.572	5.768
16	173.625	.625	163.06	21.782	6.88	50.2	95.778	5.371	.246	4.693
17	174.250	1.125	52.53	.018	-22.19	-26.2	142.242	0.865	.360	6.969
18	175.375	.625	202.96	16.154	21.17	71.0	89.272	6.581	.282	4.374
19	176.000	.500	37.24	-5.230	-24.95	-41.4	167.026	0.615	.098	8.183
20	176.500	.125	42.96	7.647	- 8.35	37.4	119.440	0.618	.256	5.852
21	176.625	1.000	116.24	-.760	7.98	- 6.8	93.138	1.719	1.434	4.563
22	177.625	3.875	135.21	-.223	13.02	4.7	90.372	2.027	1.066	4.428
23	181.500	8.000	145.80	-.283	15.51	-13.3	89.365	2.092	.520	4.379
24	189.500	.250	84.00	-1.364	- 0.37	-64.2	100.444	1.091	.291	4.921
25	189.750	.875	13.69	2.425	-12.37	-22.4	190.326	0.268	.616	9.325

Table 2.6: Averaged final data for CLE-123 at Pricetown I.

STAGE	INITIAL JD	INITIAL DURATION	ROUNDED JD	ROUNDED DURATION	TIME (HRS)	FLOW DIRECTION	SCFM IN	SCFM OUT	P/I-1	P/I-2 (PSIA)	P/I-3
1	204.520	4.000	204.500	4.000	12.30	12	13.76	33.00	400.0	163.0	326.0
2	208.520	1.600	208.500	1.750	12.30	13	30.05	60.71	338.0	154.0	149.0
3	210.320	.470	210.250	.500	7.43	21	13.10	32.81	190.0	680.0	185.0
4	210.790	.590	210.750	.625	19.00	12	26.65	40.19	364.0	164.0	252.0
5	211.380	1.340	211.375	1.375	9.10	21	14.80	22.66	172.0	258.0	176.0
6	212.720	3.270	212.750	3.250	17.20	12	14.27	18.48	232.0	152.0	183.0
7	215.990	.527	216.000	.500	23.50	21	11.69	13.42	183.0	534.0	155.0
8	216.517	1.892	216.500	1.875	12.30	12	24.03	32.49	267.0	165.0	187.0
9	218.409	4.256	218.375	4.250	9.55	31	42.30	66.42	159.0	250.0	220.0
10	222.665	1.184	222.625	1.250	16.05	13	25.97	51.13	264.0	293.0	158.0
11	223.849	.187	223.875	.125	20.30	12	36.03	79.38	306.0	193.0	193.0
12	224.036	3.419	224.000	3.375	.59	13	33.75	52.70	328.0	260.0	156.0
13	227.455	3.872	227.375	3.875	11.04	12	57.61	[illegible]	243.0	122.0	276.0
14	231.327	9.500	231.250	9.500	8.00	12	162.20	[illegible]	326.0	86.0	277.0
15	240.827	7.809	240.750	7.875	20.00	12	161.00	[illegible]	322.0	58.0	298.0
16	248.636	.732	248.625	.750	15.25	13	177.00	317.20	321.0	227.0	30.6
17	249.368	7.170	249.375	7.125	9.00	12	175.00	316.00	324.0	26.0	288.0
18	256.538	3.612	256.500	3.875	13.05	123	231.00	337.00	325.0	27.0	17.0
19	260.350	.105	260.375	.125	8.35	13	89.60	115.20	326.0	241.0	20.0
20	260.455	.106	260.500	.125	11.07	12	186.00	324.20	326.0	169.0	98.0
21	260.961	.243	260.625	.125	13.40	13	162.00	292.00	325.0	257.0	20.0
22	260.804	3.902	260.750	3.875	19.30	123	238.00	337.00	324.0	26.2	74.5
23	264.706	1.035	264.625	1.000	17.09	12	151.00	295.60	325.0	39.4	262.0
24	265.741	.854	265.625	1.000	18.00	123	210.00	485.30	260.0	126.0	79.2

Table 2.6: (Cont'd)

STAGE	ROUNDED JO	ROUNDED DURATION	COAL AFFECTED	NET H2O REACT	VOLATILE REACT	AIR LOST PER CENT	PER CENT VOLATILE REMOVED	R(VM/O)	CO/CO2	R(C/H)
1	204.500	4.000	165.79	-1.636	37.82	-31.1	77.191	2.209	.282	3.782
2	208.500	1.750	118.79	1.275	- 1.00	-22.8	100.845	1.860	.743	4.941
3	210.250	.500	185.76	17.956	34.05	47.9	81.672	6.889	.596	4.002
4	210.750	.625	87.65	-3.239	- 0.44	-16.4	100.503	1.077	.284	4.924
5	211.375	1.375	169.46	11.012	19.45	41.1	88.521	3.680	.271	4.337
6	212.750	3.250	74.39	1.808	-23.50	3.7	131.592	1.243	.194	6.447
7	216.000	.500	32.67	3.089	-32.90	2.8	200.711	0.732	.269	9.834
8	216.500	1.875	37.25	-2.826	-35.52	-19.5	195.349	0.777	.345	9.571
9	218.375	4.250	77.93	.559	-16.49	- 8.9	121.166	1.285	.766	9.937
10	222.625	1.250	90.30	-6.761	8.83	2.8	90.219	0.955	.159	4.420
11	223.875	.125	26.51	-3.243	-42.66	-106.0	260.920	0.699	.141	12.784
12	224.000	3.375	59.58	-.853	-24.91	-22.8	141.818	1.014	.375	6.948
13	227.375	3.875	89.77	.413	-12.30	-10.6	113.699	1.387	.489	5.571
14	231.250	9.500	134.16	-.933	10.95	+ 0.4	91.840	1.961	.979	4.500
15	240.750	7.875	105.27	-.817	2.80	-12.5	97.397	1.460	.567	4.769
16	248.625	.750	113.07	-.750	4.69	-19.3	95.852	1.536	.526	4.696
17	249.375	7.125	113.02	-.659	2.23	-17.9	98.028	1.601	.559	4.803
18	256.500	3.875	110.90	-.936	1.23	4.1	98.890	1.575	.631	4.849
19	260.375	.125	142.50	-.070	19.41	24.2	86.379	1.971	.403	4.232
20	260.500	.125	153.05	4.406	21.17	-13.5	86.167	2.510	.427	4.222
21	260.625	.125	131.64	.238	17.74	- 7.9	86.527	1.796	.411	4.239
22	260.750	3.875	86.70	-1.554	- 7.41	- 1.1	108.943	1.244	.554	5.318
23	264.625	1.000	111.76	-.293	5.67	-25.6	94.929	1.561	.524	4.691
24	265.625	1.000	80.52	3.293	-11.02	-44.7	113.679	1.380	.846	5.570

Table 2.7: (Cont'd)

			METHOD I				
STAGE	ROUNDED JD	ROUNDED DURATION	COAL AFFECTED	NET H2O REACT	CHAR LEFT	PER CENT CHAR REACT	$R(C/O)_1$
1	266.625	1.000	52.88	-3.971	37.41	29.235	.898
2	267.625	1.000	59.75	-2.824	45.35	24.073	.986
3	268.625	2.750	36.85	1.226	9.41	74.449	.980
4	271.375	1.250	37.10	2.003	9.42	74.597	1.010
5	272.625	.750	36.69	4.013	8.42	77.079	1.044
6	273.375	.250	39.38	4.395	14.10	64.187	1.003
7	273.625	.750	36.35	2.765	9.69	73.335	.986
8	274.375	.125	32.36	28.904	-11.85	136.648	2.611
9	274.500	.125	36.87	21.952	0.70	98.094	1.914
10	274.625	.750	38.38	.014	15.62	59.281	.876
11	275.375	3.000	46.56	.948	26.59	42.869	.966

			METHOD II			GENERAL		
STAGE	ROUNDED JD	ROUNDED DURATION	CHAR REACT	VOL MAT REACT	$R(C/O)_2$	AIR LOSS PER CENT	CO/CO2	R(C/H)
1	266.625	1.000	33.66	43.13	0.500	-45.1	3.159	7.838
2	267.625	1.000	32.86	52.90	0.484	-47.6	2.932	7.319
3	268.625	2.750	36.57	40.05	0.881	-22.2	2.015	12.382
4	271.375	1.250	36.86	42.23	0.908	-18.6	2.131	12.397
5	272.625	.750	36.43	46.85	0.951	-19.6	1.729	12.647
6	273.375	.250	34.08	50.50	0.848	-20.4	1.153	11.351
7	273.625	.750	36.06	43.40	0.881	-21.1	1.764	12.270
8	274.375	.125	42.26	104.73	2.863	-35.1	1.701	18.634
9	274.500	.125	38.98	91.88	1.902	72.3	1.486	14.759
10	274.625	.750	34.12	38.55	0.715	-10.8	1.460	10.858
11	275.375	3.000	33.83	49.10	0.672	-18.7	1.834	9.208

2.10 Thermocouple Measurement Analysis

Temperatures obtained via thermocouple measurements in monitoring wells M1, M2, M3 and M4 have been studied to determine information regarding linking and gasifying locations, temperatures of same, and if transient heat conduction methods could be used to obtain additional information [3]. The results are repeated here because of their significance.

The locations of the thermocouples in the coal seam are assumed to be in accordance with the Mound Facility report [9], as shown in Fig. 2.4 for each of the monitoring wells. Only the circled thermocouple locations are considered, as these should reflect what is occurring in the coal seam. Note that the thermocouple location numbers for M4 are different than for M1, M2 and M3.

Note also that there are really three layers of coal in the seam used for the field test. Each layer is separated from the other by a layer of mudstone, shale or equivalent, though the separation may be a graduated mixture of stone and coal.

The temperature history of the four thermocouples examined in M4 are plotted in Fig. 2.5, which is located between P/I-2 and P/I-3 (see Fig. 2.1). The highest temperatures obtained are indicative of a linking combustion temperature, but give no indication of gasification in the vicinity of M4.

The temperature histories of M1, M2 and M3 are given in Fig. 2.6, 2.7, and 2.8 in the same temperature scale but a slightly different time scale than Fig. 2.5. It is interesting to note that the responses at M2 and M3 were negligible (ambient) until

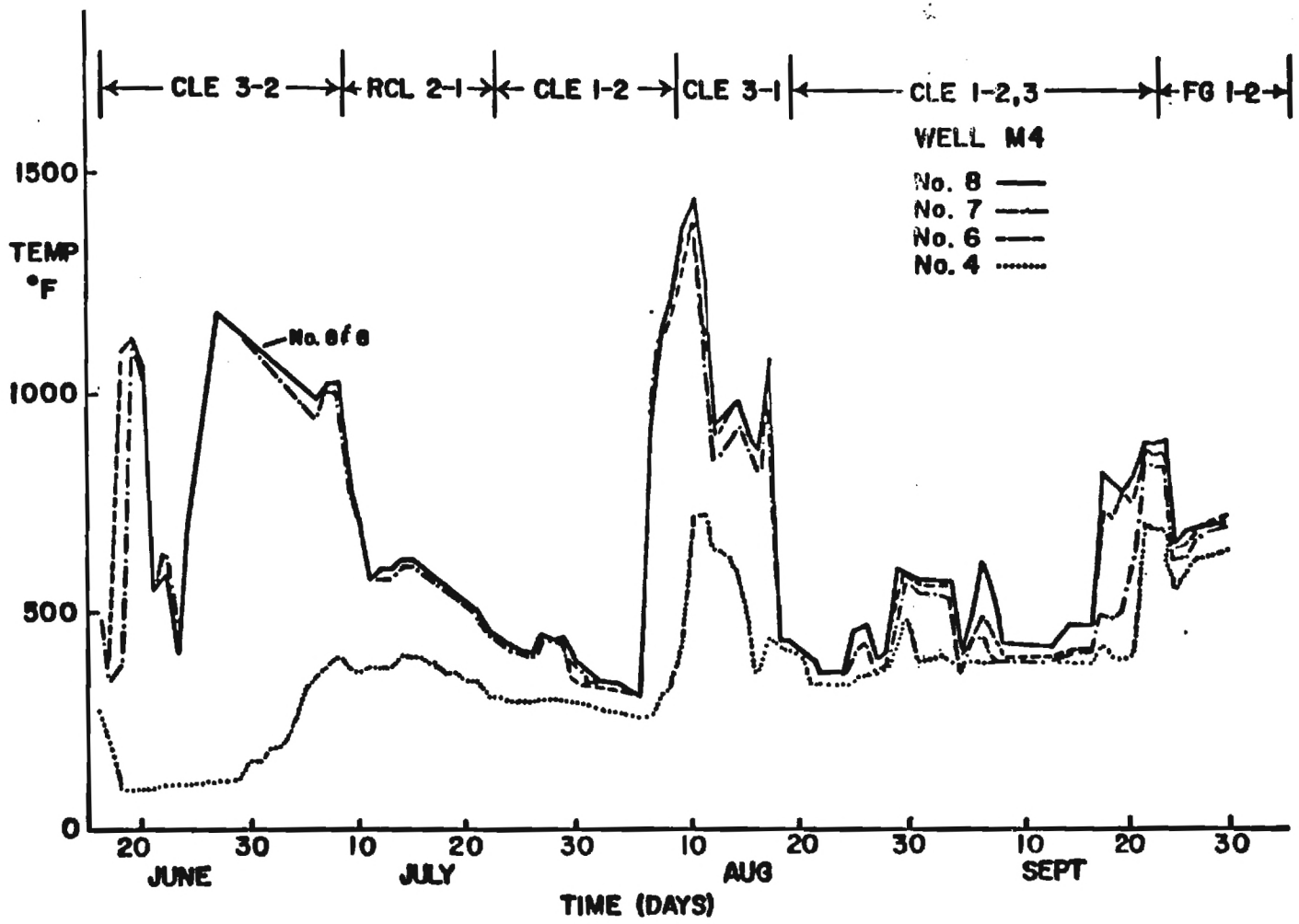
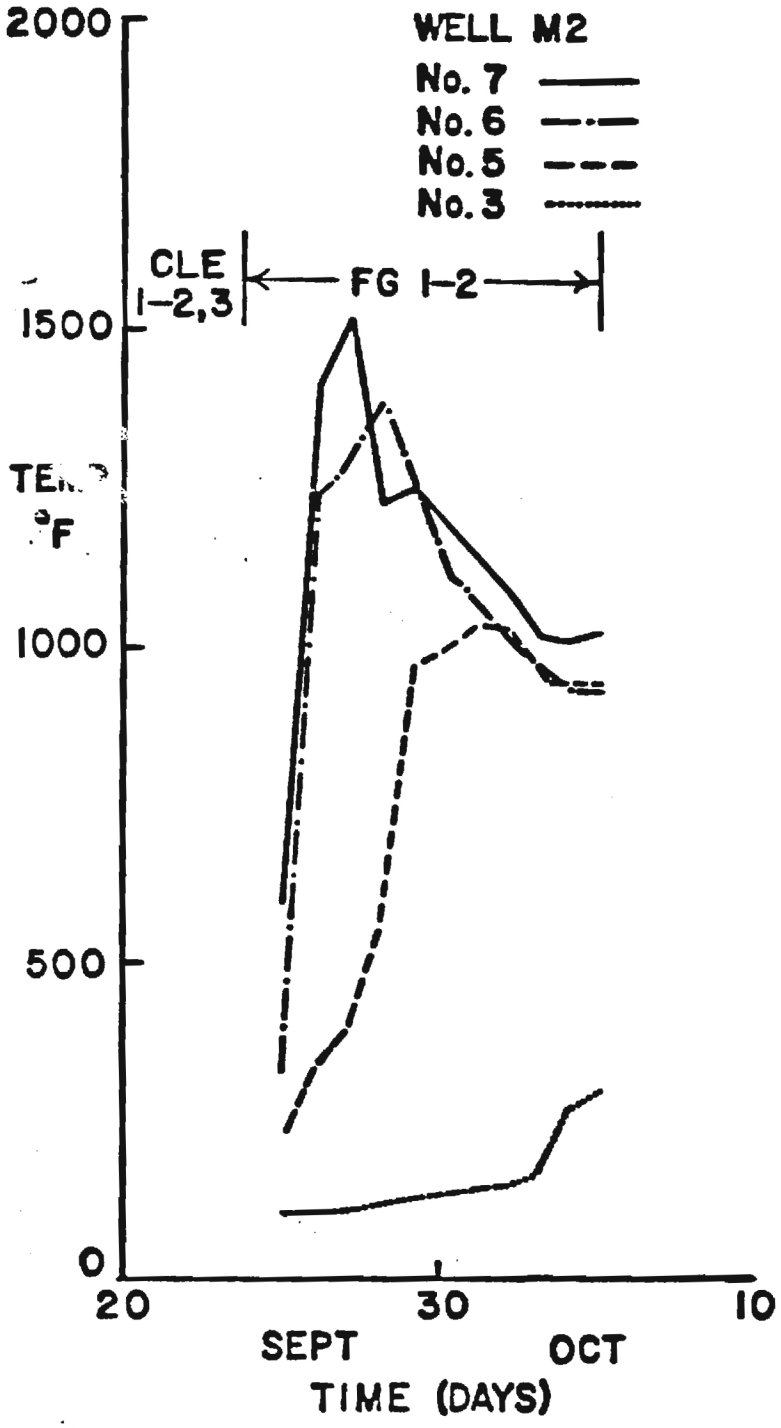


Fig. 2.5: Temperatures from selected thermocouples in monitoring well M4.



g. 2.7: Temperatures from selected thermocouples in monitoring well M2.

essentially the onset of linking or gasification adjacent to the well. This is indicated by the sharp rise from ambient to the linking combustion temperature range in Fig. 2.7 and 2.8.

The more erratic behavior of M1 thermocouples may be due to its closer proximity to the link zone and gasification regions. Nevertheless, all the figures indicate similar linking combustion temperatures and similar gasification temperatures. The figures also indicate that different layers in the coal seam became "ignited" at different times.

Smith and Stinson [10] report ignition temperatures of 1170 F (633 C) for methane, 1128 F (609 C) for carbon monoxide, 1065 F (574 C) for hydrogen, and 882 F (473 C) for ethane. They also say that flame extinction appears to be a thermal energy effect and that hydrocarbon-air flames (including methane) will extinguish at temperatures below about 2550 F (1400 C). Though the conditions in UCG may vary from the above, it does appear from Fig. 2.6 that the ignition criteria above are satisfied or that the limits of flammability are exceeded during RCL and CLE. The apparent drop off of the high temperatures during FG may be due to increasing heat losses, fluctuating "flames," and resultant extinction of combustion of the char. The quantity of tars and subsequent cooling of the bulk flow may have precluded further gasification at this time.

There are two times at which there appears to be a transient conduction effect in M1, between the middle and bottom layers, 8/5

2. It appears that the wall and gas temperatures are similarly valued during linking.

3. Gasification temperatures are in the range of 2200 to 2500 F (1205-1371 C).

4. It appears that the wall and gas temperatures are similarly valued during gasification. (This is also found to be predicted with our Models II B and II C [11]).

5. During gasification the bulk temperatures decrease in time. (This is also found with Models II B and II C [11]).

The following conclusions pertain to the burn zone layers in the coal during linking, as defined by temperatures lower than 1500 F (816 C).

6. In general, the bottom layer did not appear to undergo reverse combustion linking in both linking burns, i.e. P/I-2 to 3 and P/I-2 to 1.

7. In general, the top two layers linked at the same time with the sandwiched mudstone/shale layer equilibrating in temperature.

8. The shale layer does respond to distant thermal effects more rapidly than the coal layers; hence, it appears that the thermocouples are probably within the layers indicated on Fig. 2.4.

9. All layers burned together when gasifying.

10. When the gasification phase concluded, the gasification zone had just reached well M3 and had not yet reached, but may be about to reach well M2.

3.0 THE COMBUSTION LINK ENHANCEMENT STUDY

3.1 Introduction

The CLE model is based on gas flow through a porous duct as shown in phase 3) of Fig. 2.2. The cross section may be circular or rectangular and change in area in the axial direction. The initial geometry is determined by the RCL burn which is closed assuming a "hemisphere" on each end.

The basic mechanisms which occur are the following. Oxygen flowing through the porous duct does not react with the char during CLE. The oxygen diffuses to the link/coal wall interface by convective diffusion. Partial oxidation of the volatile matter releases thermal energy which in part devolatizes more volatile matter, in part is convected/conducted/radiated away, and in part is absorbed by the new formed char link. Here, only a simple chemical energy balance including the exothermic energy of combustion, the endothermic latent heat of the volatile matter, and the enthalpy of the char are considered. The experimental temperature histories tend to support the assumption that reactions in the bulk flow are negligible.

The CLE model formulation is analogous to the side wall burn gasification model IIIA[2]. The cavity is replaced by a porous link and the appropriate relations are inserted in the heat and mass transfer subroutine. Other modifications include the capability of injecting into any of the three Pricetown I production/injection wells (shown in Fig. 2.1) and simultaneous production from the other

3.2 Affected Region Growth

The change in the radius (or half-width) of the link during the CLE phase in a "hemispherical" or "cylindrical" sector is obtained from

$$\Delta r = \dot{m}_{vm,w}/\rho_{vm}\, A_w \ , \tag{3.1}$$

where

$$\dot{m}_{vm,w} = R_{vm/o}\, \dot{m}_{ox,w} \ . \tag{3.2}$$

The relations necessary to calculate $R_{vm/o}$ and $\dot{m}_{ox,w}$ are given in sections 3.3 and 3.4, respectively.

3.3 Volatile Matter Consumption

In CLE the mass ratio of volatile matter removed to oxygen supplied is the sum of that oxidized and devolatilized;

$$R_{vm/o} = R_{vm/o,ox} + R_{vm/o,de} \ , \tag{3.3}$$

where by stoichiometric analysis,

$$R_{vm/o,ox} = \frac{1}{(1.33Y_C + 8Y_H + Y_S - Y_{ox})_{vm}} \ , \tag{3.4}$$

and it is assumed that:

$$Y_{C,vm} = Y_C - Y_{FC};\ Y_{H,vm} = Y_H \ ; \tag{3.5}$$

$$Y_{S,vm} = Y_S \ ;\ Y_{o,vm} = Y_{ox} \ .$$

$$CO/CO_2 = 10^{3.4} \exp [-12,400/RT] \qquad (3.9)$$

in the temperature range of 460 to 900 C.

3.4 Oxygen Mass Transfer to the Wall

Flow through porous media is often characterized by the Reynolds number based on the superficial velocity (100% porous and pore or pellet size. In CLE the pores are small enough that $Re_{d_p} < 5$ which characterizes a truly laminar range in which D'Arcy's Law appears to hold [13]. Under these conditions the velocity profile is essentially a slug flow profile and viscous entrance region considerations are a moot point [3, Section 6.1.2].

The thermal and oxygen mass transfer boundary layers will develop over several duct diameters but in fewer diameters than for an open tube. In this work, the largest duct length to diameter is about 60÷2 = 30 which is approximately when the heat and mass transfer boundary layers become fully developed.

Previously [3] we reported some of the difficulties in understanding the mechanisms governing the convective flow processes in the porous link zone. With the corrected final field test data and additional analysis we have a better idea of the probable mechanisms during CLE. The details of the calculations are left to Appendix .1, but the overview will be presented here.

Correction of a sign error in the forced convection, porous edia Nusselt No. relation [3, Eqn. 6.27] resulted in a more variable entrance region correlation which is a function of the Graetz

Applying $Pe^2 \propto Ra$

$$Nu_x = 2.126\ Pe_x^{.317} \sim (1.39\ Ra_x^{1/6})^2 \qquad (3.16)$$

where the 1/6 exponent represents a sub-laminar range in natural convection.

The final Nusselt No. relations as determined in Appendix 5.1 by analogy and comparison with the field test data are:

$$\overline{Nu}_x = 1.67\ Ra_x^{1/6} \quad ; \quad Ra_x < 10^4 \text{ (sub-laminar)} \quad , \qquad (3.17)$$

$$\overline{Nu}_x = 0.15\ Ra_x^{1/4} \quad ; \quad 10^4 \leq Ra_x \leq 10^9 \text{ (laminar)} \quad , \qquad (3.18)$$

$$\overline{Nu}_x = 0.10\ Ra_x^{1/3} \quad ; \quad 10^9 < Ra_x\ 10^{12} \text{ (turbulent)} \quad . \qquad (3.19)$$

qns. (3.17) and (3.18) are in good agreement with the experiment. he coefficient of (3.17) could vary by a factor of two with a egligible change in the results. Increasing the coefficient in 3.18) by 40% yields a coal consumption error of only 1% but a 10% arger maximum width of the link zone. There is no data to match ıd therefore check (3.19).

While relations (3.17-19) were evolving it became obvious that ıe characteristic length for natural convection was not the total nk zone height. When used it would yield boundary layer velocities ceeding velocities obtained in the FG void cavity. Also the mass ansfer coefficient became so large that the oxygen was totally con-

3.5 Special Features of the CLE Model

The methods for applying the relations above into the model are analogous to the methods used in the forward gasification model IIIA discussed elsewhere [2].

The CLE model now includes the experimental mixing feature which accounts for the imperfect mixing of fresh blast and devolatilized material in the swirling flows. The model also includes a least squares polynomial fitting of the width to smooth the positive feedback in the "hemisphere" region.

The ability to switch injection and production wells among the three vertical wells in a linked vertical well geometry such as at Pricetown I is included. This ability required the formulation of a "hemispherical" production region in addition to the existing "hemispherical" injection region. The ability to switch or merge "cylindrical" regions to "hemispherical" regions and vice versa is also included in the CLE model. The fine details in this regard are included as Appendix 5.2 which is taken from a special problem report [14]. A listing of the CLE computer program for Pricetown I is given in Appendix 5.7 with most of the nomenclature given in Appendicies 5.2 and 5.6.

.6 RCL Link Diameters

The effective link diameter is calculated for the RCL-23 and RCL-12 phases from the volatile matter affected based on the air injected:

of the M4 thermocouples reached devolatilization temperatures above 1000°F on or about June 19 (10 days after ignition) during the CLE phase between P/I-2 and P/I-3. Using the CLE mass transfer coefficient values obtained from equations (3.17) and (3.20) in the CLE model to enlarge the diameter of the initial link formed by RCL (originally 2.39 feet in diameter) we find that the enlarged link has an equivalent diameter of 3.0 ft. This locates the axis approximately 1.5 ft from M4 as shown in Fig. 3.1. A line through P/I-3 and parallel to the face cleat direction is 4.8 ft from M4 and hence 3.3 ft from the predicted axis in the vicinity of M4. Note that the predicted axis essentially coincides with a line through P/I-1 and parallel to the face cleat direction. Unfortunately, the model finds a different axis for the P/I-1 to P/I-2 link as discussed in the next paragraph.

The location of the axis of the link between P/I-1 and P/I-2 is obtained similarly. Fig. 2.6 shows that devolatilization temperature values reached M1 about August 12 (64 days after initial ignition) and possibly on July 29 (50 days after initial ignition and 20 days after igniting RCL-1,2). It is notable that reversal of the flow was attempted, starting on July 29, without any substantial success with injection from P/I-2. (See stages 1-20 in Table 2.4.) In the 14 day period between July 29 and August 12, injection occurred into P/I-1 for only about five days. Since injection affects the cavity mostly near the injection well, whereas the growth at M1 is slow, the diameters after 50 and 64 days are 0 and 3.3 ft, respectively. Starting with the RCL link diameter

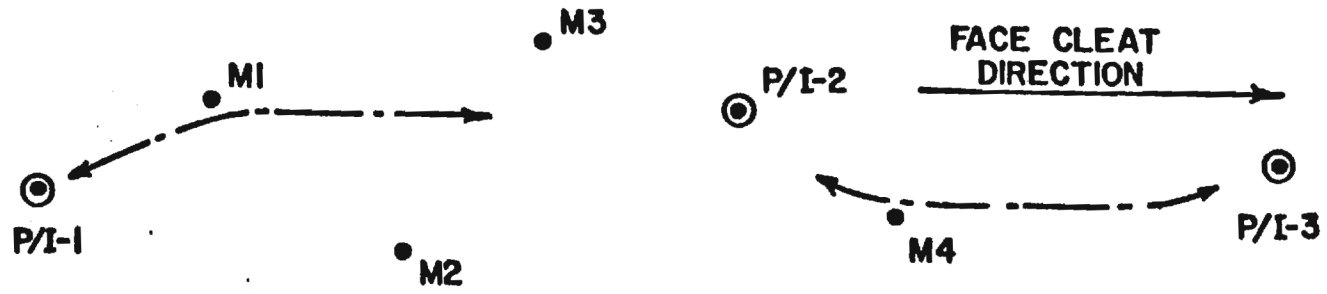


Fig. 3.1: Plot of probable link zone axis locations based on M1 and M4 monitoring well temperatures, face cleat direction and ratio of face and butt cleat permeabilities.

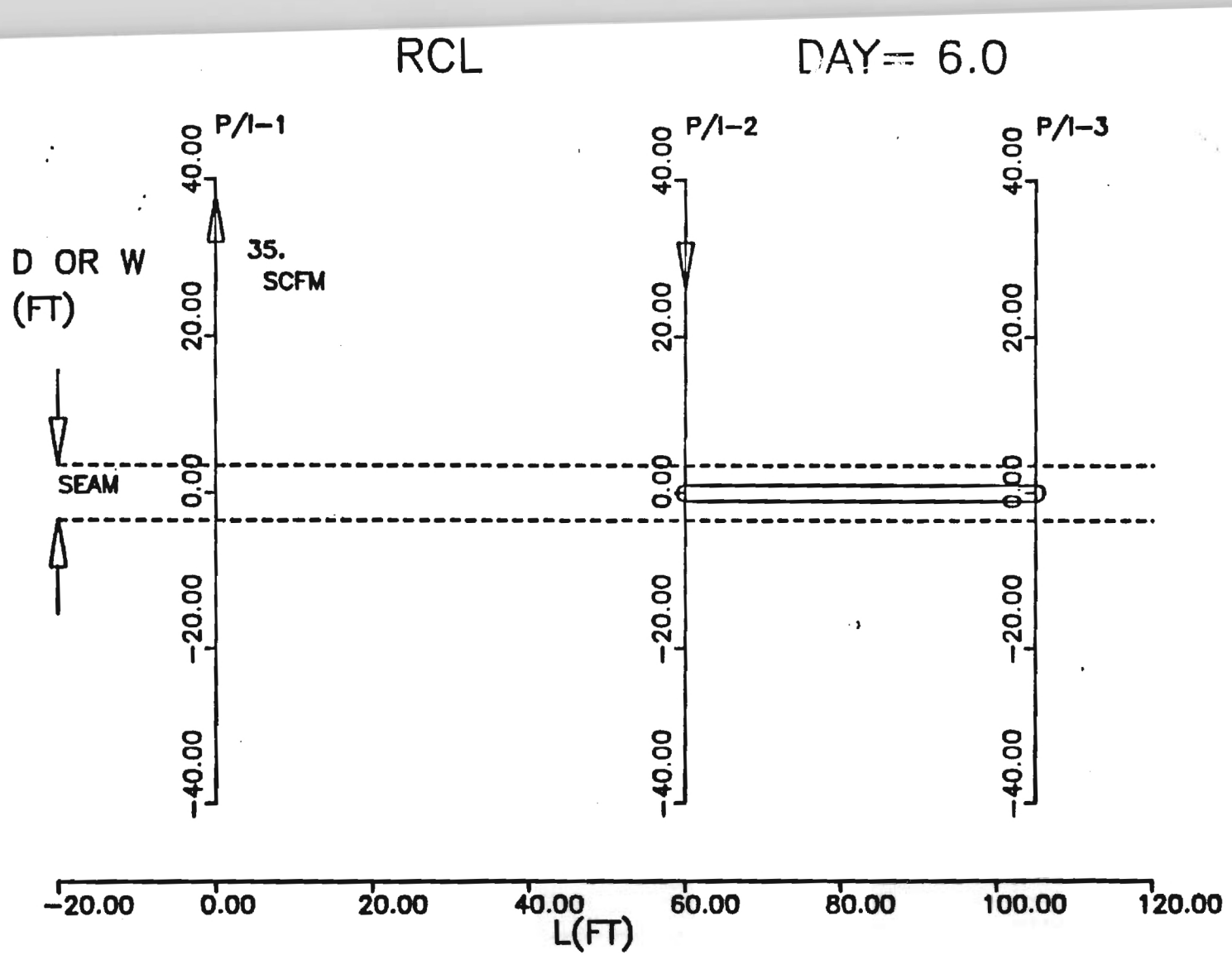


Fig. 3.2: Elevation view after RCL-23 (6 days).

Finally at Day 16 (6/25) air was able to be injected into P/I-2, which proceeded until Day 30.1 (7/9). The resulting link zone shape is shown in Fig. 3.4. The link cross section is assumed circular until the burden is reached, whereupon the cross section becomes rectangular. In plan view this occurs whenever the width is more than the seven ft. (here) or the effective seam thickness. RCL from P/I-2 to P/I-1 started on Day 30.1 (7/19), proceeded until Day 44 (7/23), and developed an average link zone diameter of 2.56 ft. Fig. 3.5 shows the RCL elevation view, as well as the plan view between P/I-2 and P/I-3.

CLE from P/I-1 to P/I-2 occurred from Day 44 to Day 58.5 (8/6) with attempts to reverse the flow with limited success. CLE from P/I-3 to P/I-1 started on Day 58.5 and ended Day 61 (8/10) with little change in the link zone shape. All subsequent flows were injected into P/I-1. From Day 61 to Day 70.8 (8/19) the flow rate was doubled by dropping the back pressure and/or increasing the injection pressure. Nevertheless, the low flow rates had not made significant impact on link zone development by the end of phase CLE-123A (Day 70.8) as shown in Fig. 3.6.

During CLE-123A, the back pressure was further lowered, which more than doubled the flow rate for a period of more than 25 days at an average of 182 SCFM with cavity shapes shown in Fig. 3.7 for Day 90 and Fig. 3.8 for Day 106.1 (9/23). At this time the flow was temporarily reversed in an attempt to enhance the flow. A seven fold increase in flow and forward gasification followed.

Consider the predicted link zone shape just prior to gasifica-

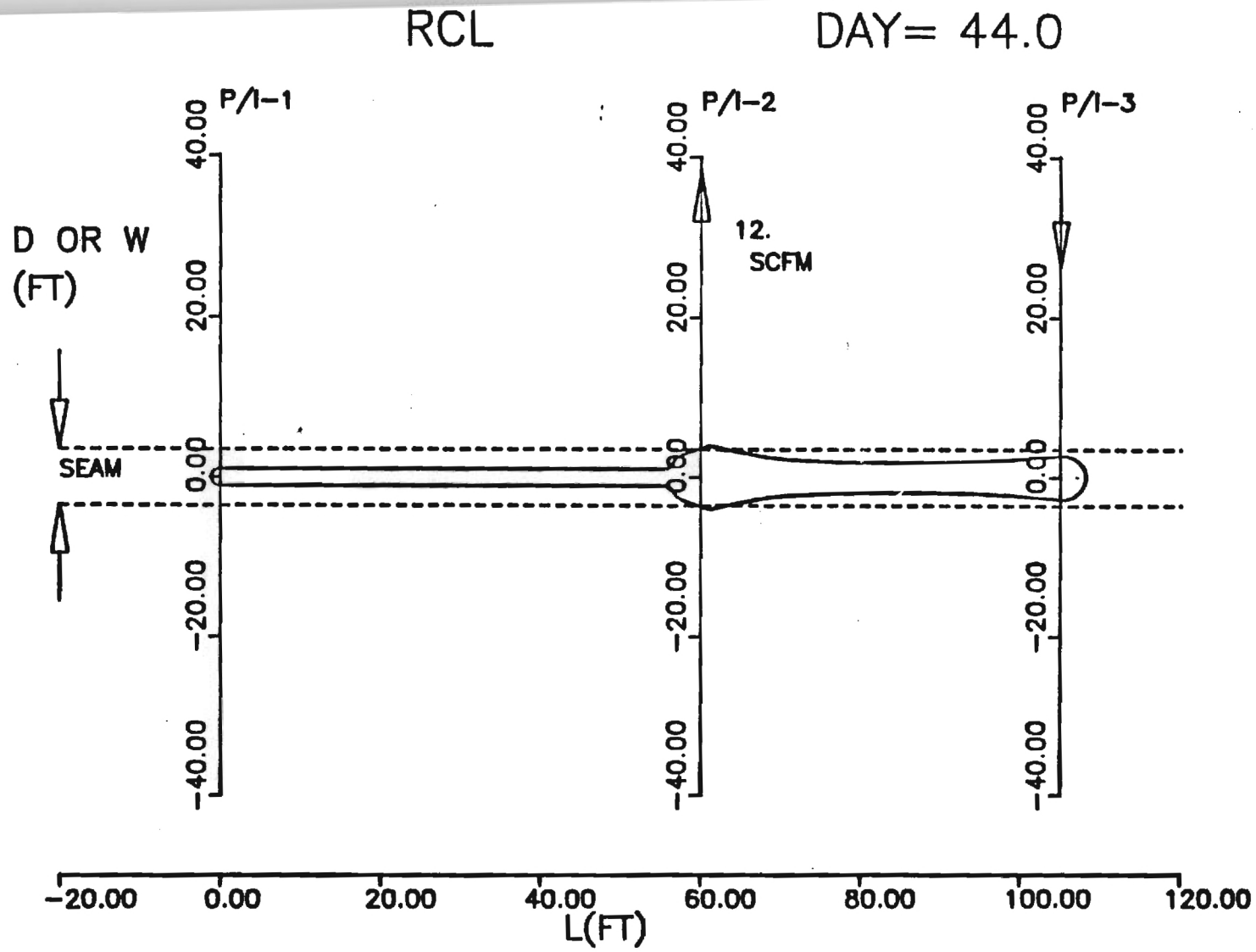


Fig. 3.5: Elevation view after RCL-12 (44 days).

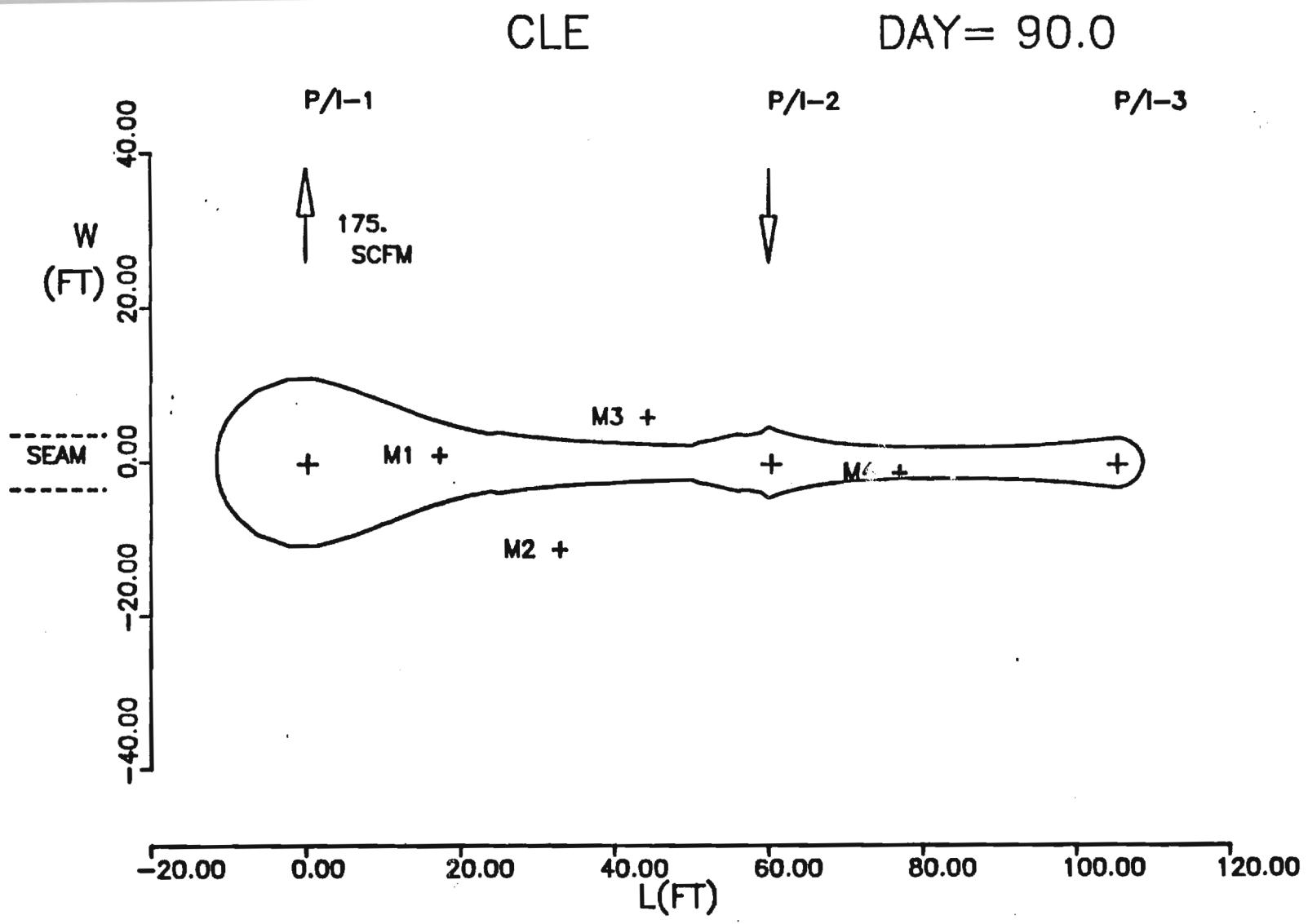


Fig. 3.7: Plan view of CLE-123B after 90 days.

tion in Fig. 3.8. M1 and M4 are within the link, M3 is closer to the link than M2. The M1 temperature plot in Fig. 2.6 showed steady temperatures over 1000 F from about Day 61 until forward gasification occurred. This suggests that there is extensive oxidation and devolatilization all around the link-coal interface and a significant amount of mixing of the blast with the oxidized and devolatilized products. M4 heated up only when injection through P/I-3 occurred as shown in Fig. 2.5.

Finally, devolatilization at M2 and M3 did not occur until after forward gasification had commenced on Day 106.1 (9/23) as shown in Figs. 2.7 and 2.8, in agreement with Fig. 3.8. The CLE model has enabled us to estimate the approximate location of the link zone axes between P/I-1 and 2, as well as between P/I-2 and 3.

[19]. The sign corrections did not appear to alter the results significantly.

A more significant modification occurs in the energy balance iteration procedure for calculating wall and bulk or combustion gas temperatures. Kunselman, Fausett and Mones [20] used the FG model in a comparison with other FG models and had difficulty obtaining solutions (convergence) over the duration of a burn. We had not had this problem with runs of Hanna II, phase 2 data [11] nor the preliminary Pricetown I data [3]. We did find the same problem when we input the final Pricetown I data as per Table 2.7. The temperature iteration scheme was subsequently modified to give convergence at lower temperatures (otherwise it blew up) and also optimized to give fewer iterations to convergence and hence give shorter run times. The Pricetown I data of Table 2.7 with 27 distinct time intervals requires about 308 seconds of CPU time on a Cyber 170 with the optical thin gas, wall-to-wall radiation mode and about 60 seconds for the optically thick gas (no wall-to-wall shape factors calculated) radiation assumption. Additional improvements could include second order convergence on wall temperature. The values converge over a short range of temperatures and the present scheme results in greater scatter than desired.

Other modifications included a floating, burden wall temperature. Attempts to calculate the burden wall temperature via the heat transfer to the exposed burden were unsuccessful for a lack of time. Previously the exposed burden wall was fixed at 1000°R. As compromise, the present program uses the average of the reacting

ties between sections and positive feedback on the mass transfer coefficients. Various types of polynomial and spline fit procedures were attempted with the simplest appearing to be the best, overall. The present procedure subroutine SMOOTH smooths the diameters after each time interval by simply averaging the adjacent values with twice the value of interest as described by Bevington [21].

We have also added a 3-D plot of the cavity or affected region. When an orthogonal projection at 45° is used, a cavity with either circular or rectangular cross sections can be expressed mathematically in simple terms, as given in Program UCG3D in Appendix 5.9. Stringers can be connected longitudinally to outline the shape (in a variety of ways) as shown in Fig. 1.7. Program UCG3D could be included as a subroutine in the interactive mode to show the cavity geometry during a burn.

.3 Gasification of Char

The reasons for modifying the FG program to include the relations for the gasification of char or coke, as well as the gasification of coal were given in Section 2.7 which also presented the appropriate relations for $R_{ch/o}$, $R_{vm/o}$ and $R_{c/o}$. The $R_{ch/o}$ values are used in the FG program if the KCHR flag equals unity and $R_{c/o}$ values are used if KCHR = 2. The latter is set if the cavity is within $d_{z,ch}$ of the virgin coal interface. The value of $d_{z,ch}$ can be determined by matching the mass of volatile matter removed via the program (including downstream devolatilization) to field test data at different times. In the present work, it is found that

between the end of the cavity and the production well, at the end of each time interval. As the bulk flow leaves the cavity it is dispersed over the link zone cross section. The appropriate heat transfer coefficients are therefore calculated via subroutine HTRL via the CLE model. The energy balance for each section in the link zone includes the convective heat transfer to the virgin coal interface, latent enthalpy of vaporization of both coal moisture and volatile matter, sensible enthalpy of the remaining char/ash, and volatile matter removed. Consideration of the energy rate equation over a given time interval Δt yields the mass of volatile matter devolatilized as

$$m_{vm} = \frac{Y_{vm}\, h_C\, A_{w,R}\, (T_b - T_{w,coal})\, \Delta t}{Y_M\, h_{fg,H2O,T(p)} + Y_{vm}\, h_{sg,vm} + C_{p,coal}(T_b - T_{w,coal})} \quad (4.2)$$

The terms in the denominator each increase by an order of magnitude over the one to its left, indicating that the sensible heat of the coal to be devolatilized is the most significant energy absorber. Values of $h_{sg,vm}$ are approximated from values for complex hydrocarbons [22]. Most devolatilization information gives composition of the products versus temperature, but no information on the energy required.

The decrease in temperature of the bulk gas is calculated from the inlet enthalpy and convective heat transfer to the virgin coal walls and burden walls (if exposed). The leaving bulk temperature is then

and other constants are resident in the program, $R_{c/o,2}$ is calculated from the above.

Most UCG cavities are large enough that the turbulent natural convection flow regime is activated though the forced convection is at laminar Re_x. Using the data of Table 2.7 as read input, the program is run with (variable) constants set at:

$d_{z,ch}$ (= DZCH) = 1.0 ft

N_o (= CIRCT1) = 12.0 ; (gives 24 in hemisphere)

$R_{ch,Nr}$ (= 1 - $R_{ch,R}$ = RCHNR) = 0.0 ; (all char reacting)

$Nu_{nc,turb}$ (= ANUN) = $C_{nc,t}$ $Ra^{n_{nc,t}}$ = $0.1R_a^{0.333}$.

ubsequent runs are made to determine the optimum values of $R_{ch,NR}$, $_{nc,t}$ and N_o based on where the cavity is "known" to be (i.e., at ell M3 after 11.75 days of FG). Finally, the value of $d_{z,ch}$ is etermined by trial and error, matching volatile matter consumption otals via the FG computer model with those calculated from product as composition.

The resulting values for the present data runs are:

$d_{z,ch}$ = 2.04 ft

N_o = 12

$R_{ch,NR}$ = 0.80 ; therefore $R_{ch,R}$ = .20

$Nu_{nc,turb}$ = $0.1\ Ra^{0.350}$.

actically speaking, this means that there is about a 2 ft char rder between the cavity and the virgin coal at locations where the vity got close enough to the coal to affect the volatile matter. y 20% of the char is removed from the coal or char link zone.

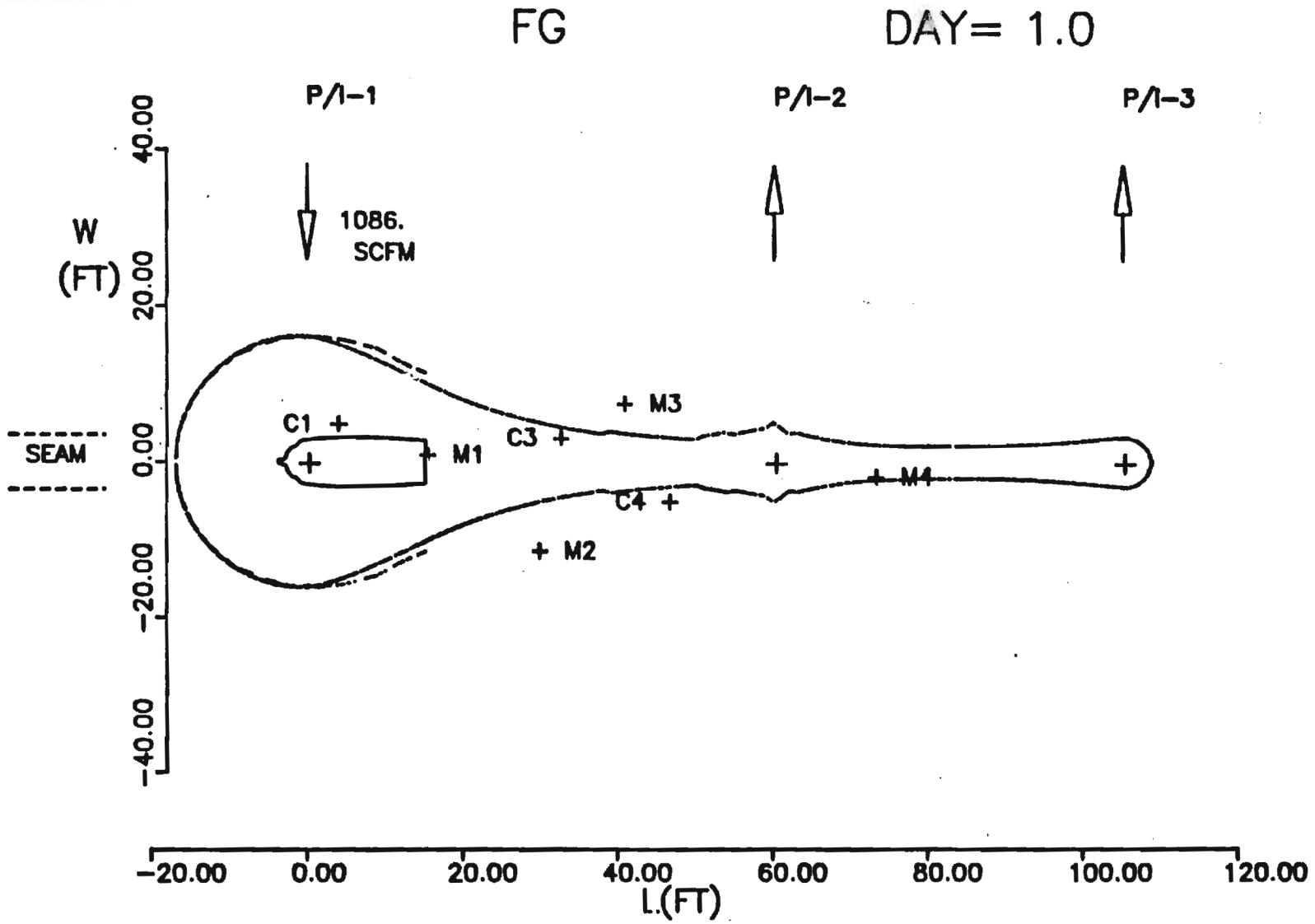


Fig. 4.1: Plan view of forward gasification (Day 1).

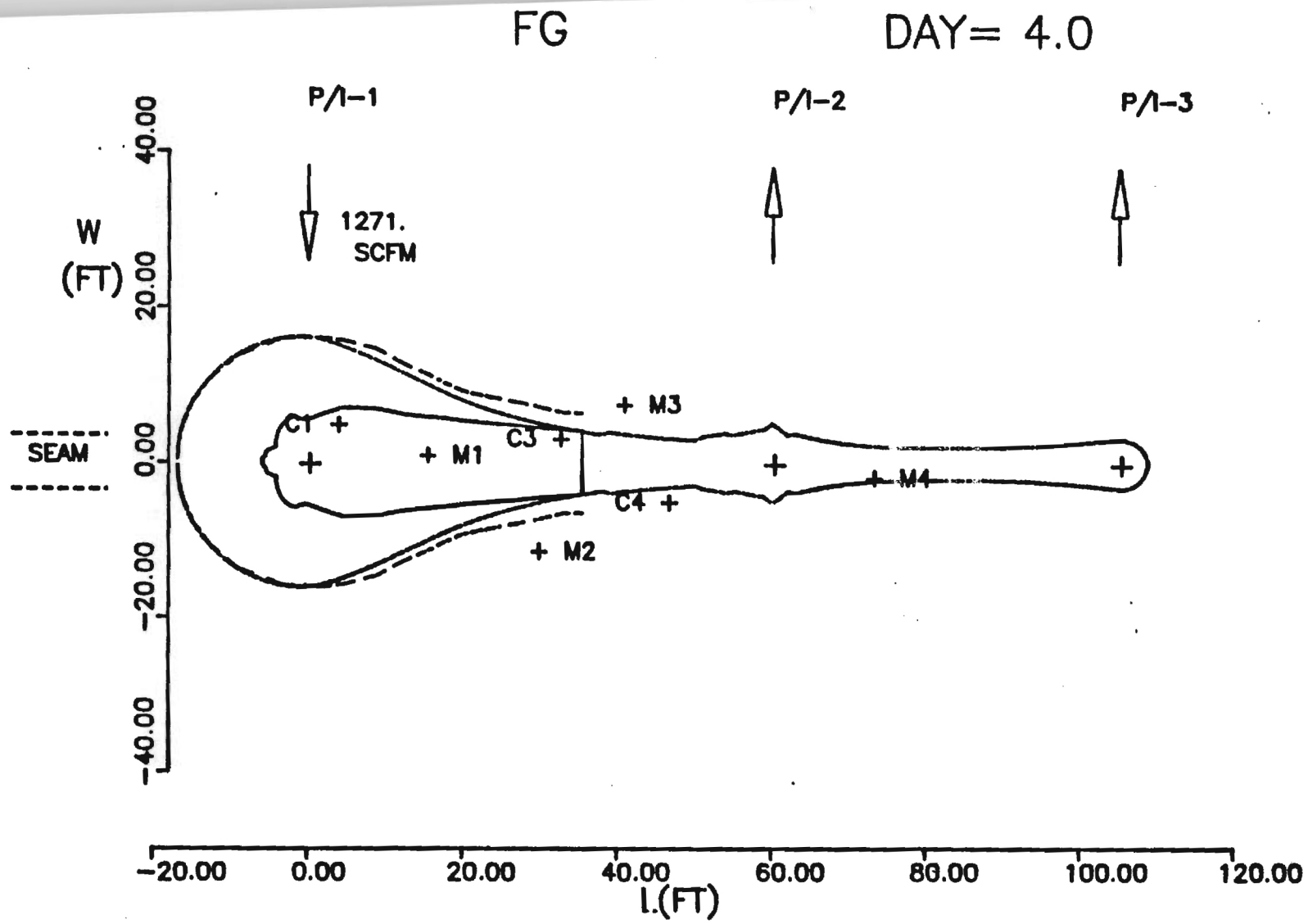


Fig. 4.3: Plan view of forward gasification (Day 4).

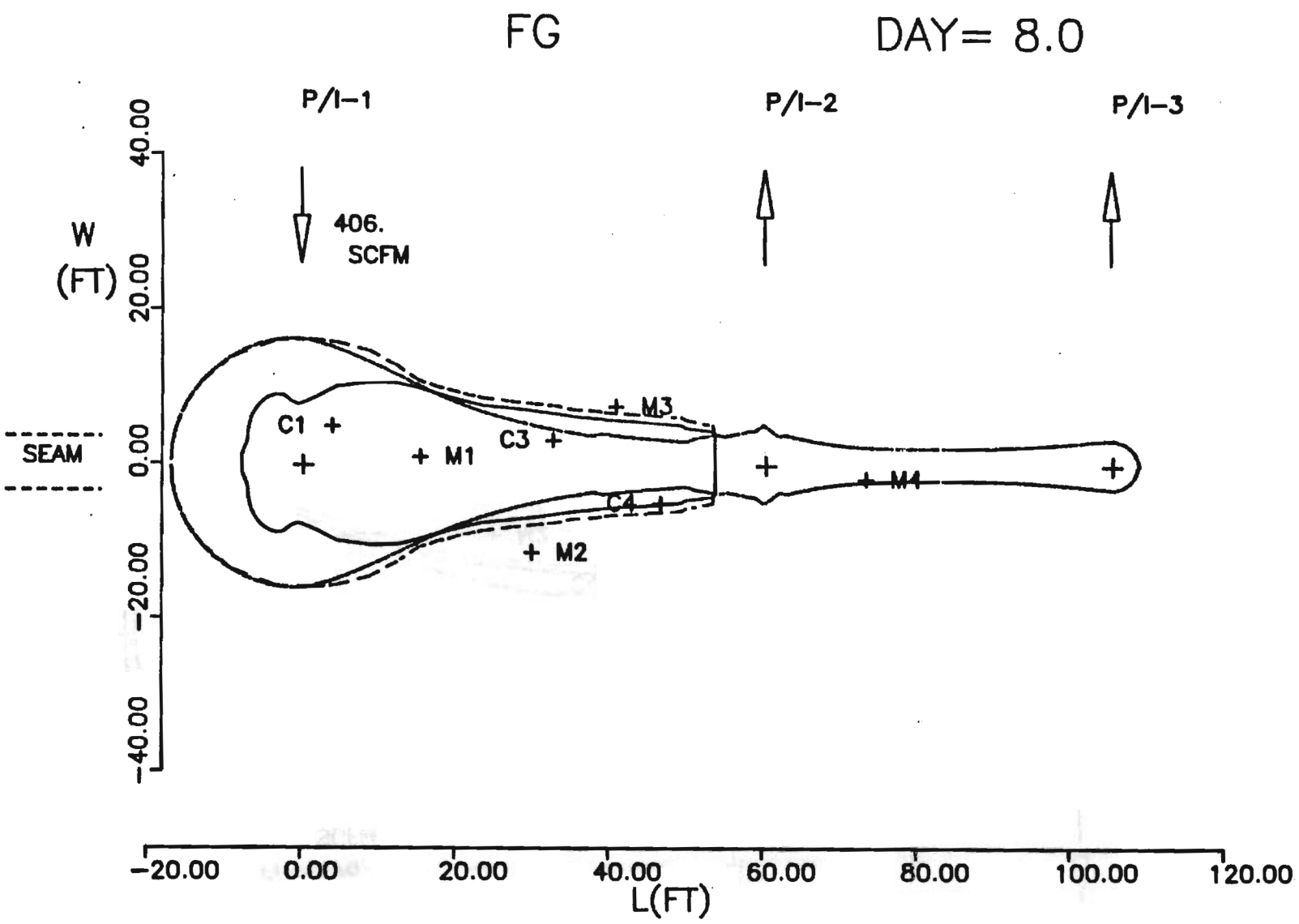


Fig. 4.5: Plan view of forward gasification (Day 8).

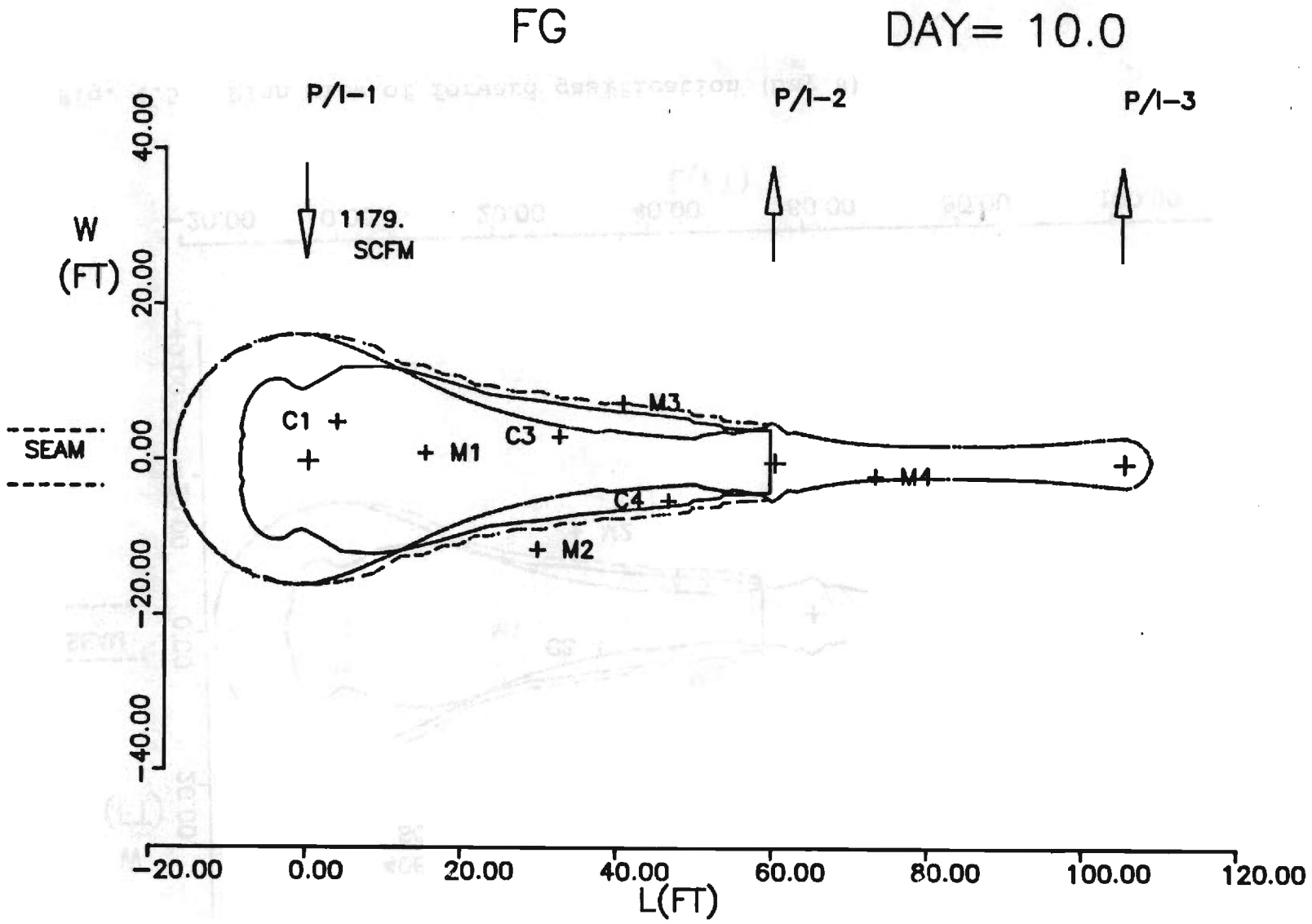


Fig. 4.6: Plan view of forward gasification (Day 10).

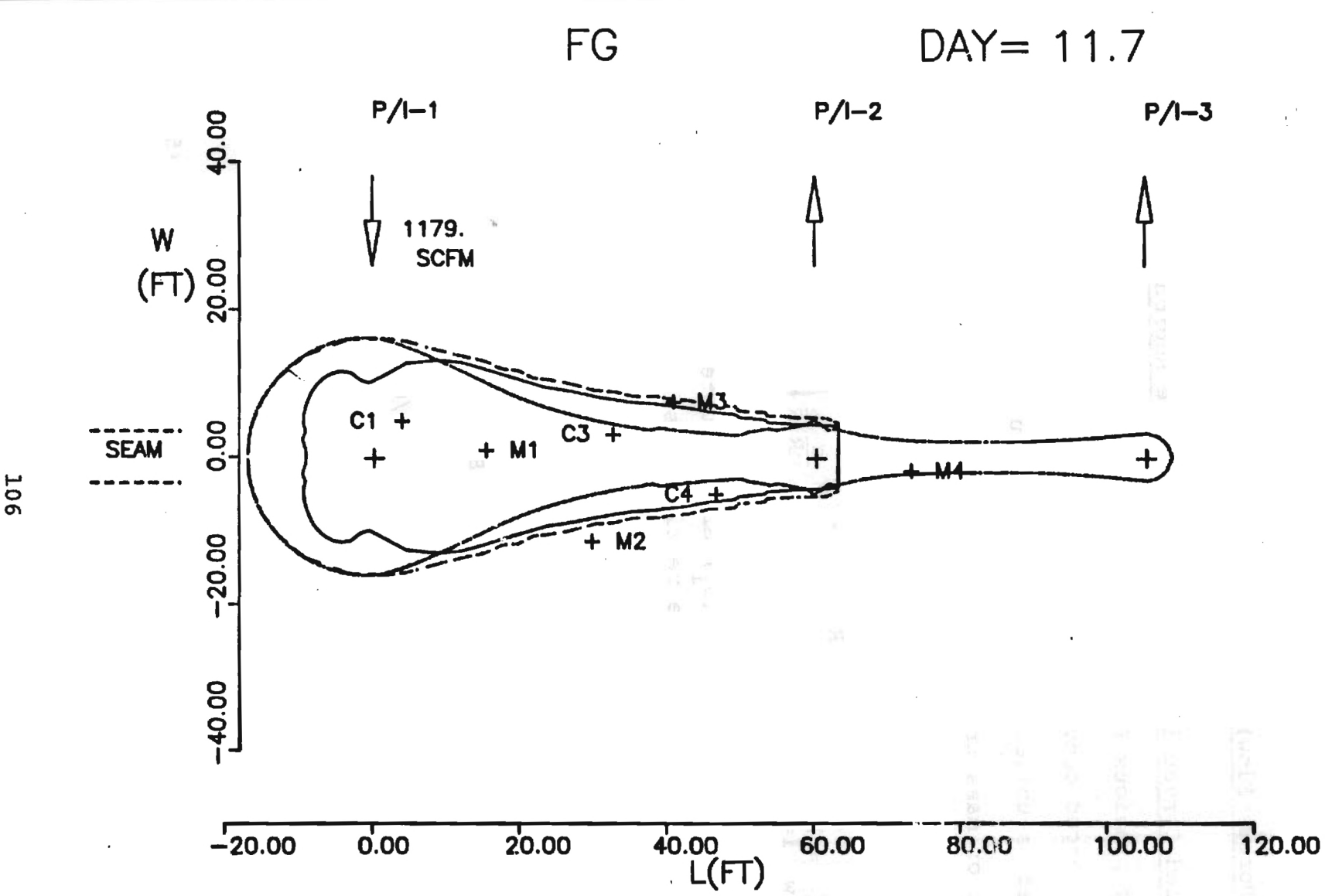


Fig. 4.7: Plan view of forward gasification (Day 11.75).

5.0 APPENDIX

5.1 CLE (Porous Flow) Nusselt No. Relations

5.1.1 Forced Convection in a Porous Entrance Region

In the previous Final Report [3] it was found that the velocity profile in forced convection through the porous link zone could be approximated as uniform flow at velocity u with negligible effect on the heat or mass transfer. The dimensionless temperature profile was also found to be

$$\frac{\theta}{\theta_o} = \frac{T-T_w}{T_o-T_w} = \sum_{i=1} \frac{2\, J_o[\beta_i r/R]}{\beta_i\, J_1[\beta_i]} \exp\left[-\beta_i^2 \frac{\alpha}{uR} \frac{x}{R}\right] , \qquad (5.1)$$

where the constants β_i and $J_1(\beta_i)$ are evaluated is before. Employing $Gz_d = Pe_d\, d/X'$ (5.1) can be rewritten as

$$\begin{aligned}\frac{\theta}{\theta_o} = {} & 1.602\, J_o[4.810\, r/d] \exp[-23.14/Gz] \\ & - 1.065\, J_o[11.02\, or/d] \exp[-121.89/Gz] \\ & + 0.8512\, J_o[17.308\, r/d] \exp[-299.57/Gz] \\ & - 0.7295\, J_o[23.584\, r/d] \exp[-556.21/Gz] \\ & + 0.6487\, J_o[29.862\, r/d] \exp[-891.74/Gz] \\ & - \ldots \qquad . \end{aligned} \qquad (5.2)$$

The Nusselt number is then calculated as

$$Nu_d = \frac{h_c d}{k_{eff}} = \frac{-k_{eff}\ \partial T/\partial r|_w}{T_o - T_w}\ \frac{d}{k_{eff}} = 4\ \Sigma\ \exp\ [-4\beta_i^2/Gz]$$

$$= 4(\exp[-23.14/Gz] + \exp[-121.89/Gz]$$

$$+ \exp[-299.57/Gz] + \exp[-556.21/Gz]$$

$$+ \exp[-881.74/Gz] + \ldots \quad , \qquad (5.3)$$

where (5.3) is the corrected version of (6.27) in [3]. A plot of Nu_d versus Gz_d in Fig. 5.1 shows the asymptotic limiting values of Nu at high and low Gz values of 33.06 and 5.874, respectively. The former applies to short tubes or regions near the entrance while the latter applies to long tubes. The computer program has the capability to calculate Nu(Gz) and the mass transfer coefficient for forced convection through the porous link zone using (3.10)-(3.12) dependent upon the Gz value. The calculation is not included because h_m values are found to be negligible compared to the natural convection values.

Regions of interest cover $1 \lesssim x/d \lesssim 10$ which with Pe ~ 3000 gives $300 \lesssim Gz \lesssim 3000$. Fitting (3.11) to a more convenient form (for comparison purposes later) gives

$$Nu_d = C\ Gz_d^n = 2.125\ Gz_d^{0.317} \quad . \qquad (5.4)$$

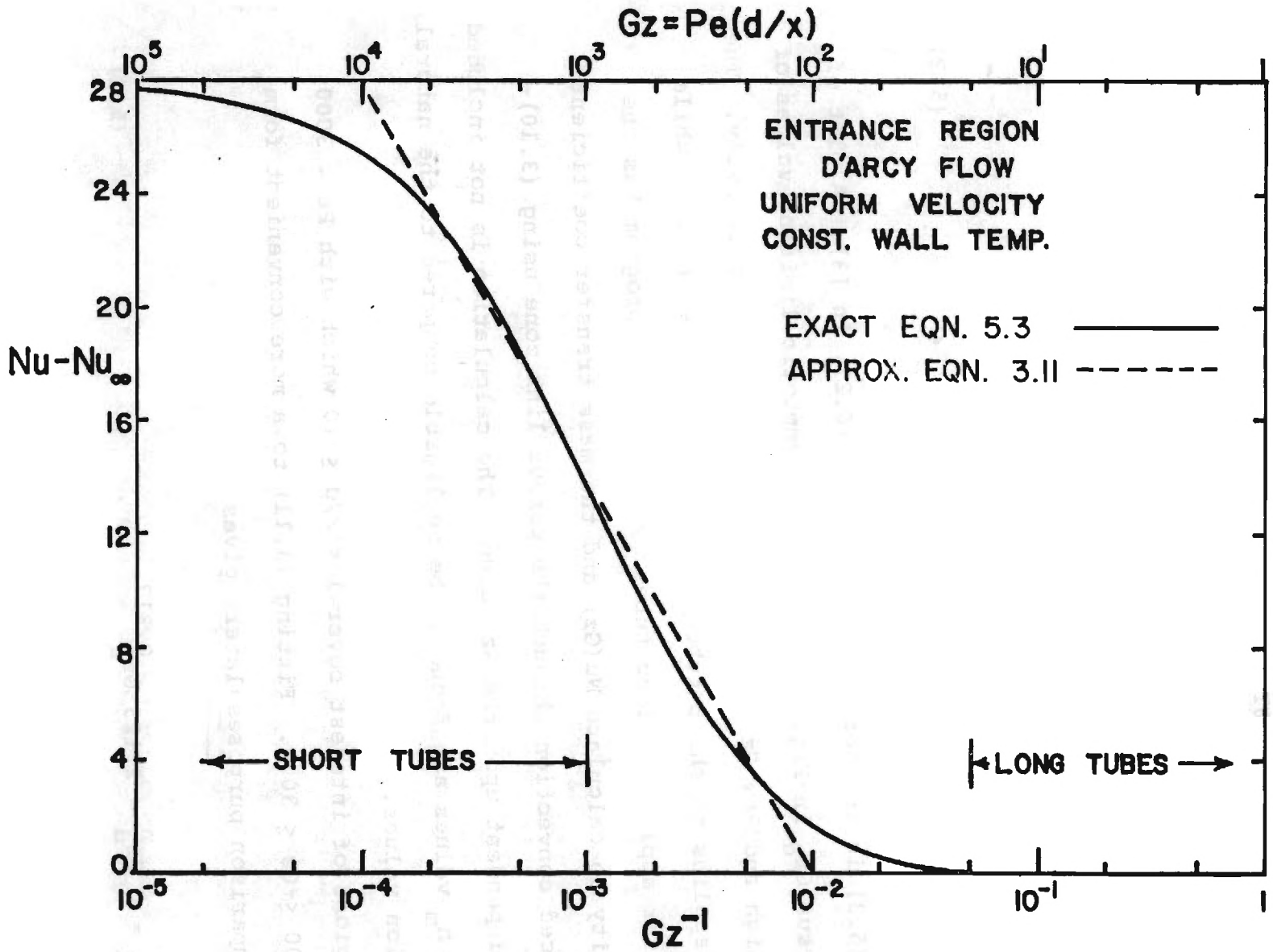


Fig. 5.1: Nu versus Gz for the entrance region in D'Arcy flow through porous media.

Then in an extrance region

$$Nu_x = (x/d)Nu_d = 2.126\ Pe_d^{.317}\ (x/d)^{1\ -0.317}\ ,$$

$$= 2.126\ Pe_x^{.317}\ (x/d)^{.366} \simeq 2.126\ Pe_x^{1/3}\ . \qquad (5.5)$$

The last approximation results because $x/d \sim 1$ in regions of major interst. The exponent represents a sub-laminar flow regime as shown below.

Fitting a similar region with a laminar correlation

$$Nu_d = 0.601\ Gz_d^{0.5} = 0.601\ Pe_d^{0.5}\ (d/x)^{0.5}\ ;$$

hence,

$$Nu_x = (x/d)\ Nu_d = 0.601\ Pe_x^{0.5}\ . \qquad (5.6)$$

5.1.2 Reynolds and Rayleigh No. Ranges

In porous flows, approximate Re ranges based on the pore or grain diameter are estimated as follows [13].

Re(dp)	Mode
0-5	laminar
5-200	laminar + inertial
200-2000	"turbulent"

For natural convection over a vertical plate, ranges are based on the plate height, L, [23,24].

Ra_L	$Ra_L^{1/2} \sim Pe \sim Re$	Mode	$\overline{Nu}_L$
$10^{-1} - 10^4$	$.3 - 10^2$	"sub-laminar"	$1.26\ RA^{1/6}$
$10^4 - 10^9$	$10^2 - 3 \times 10^4$	laminar	$0.59\ Ra^{1/4}$
$10^9 - 10^{12}$	$3 \times 10^4 - 10^6$	turbulent	$0.10\ Ra^{1/3}$

while the sub-laminar coefficient, 1.26, is calculated from McAdams [24] graph.

Other correlations, such as forced convection over a horizontal cylinder show similar ranges and Nu correlations, as shown below [23,25,26].

Re_d	Mode	$\overline{Nu}_d$
0.4 - 4	sub-laminar	$0.989\ Pe^{1/3} \sim (0.99\ Pe^{1/6})^2$
4 - 40	-	$0.911\ Pe^{2/5}$
40-4000	laminar	$0.683\ Pe^{1/2} \sim (0.83\ Pe^{1/4})^2$
$4000-4\times10^4$	-	$0.193\ Pe^{3/5}$
$4\times10^4 - 4\times10^5$	turbulent	$0.0266\ Pe^{4/5} \sim (0.16 Pe^{0.4})^2$

5.1.3 Local and Average Nusselt Nos.

If $Nu_x = C_1\ Pe_x^n$, then

$$h_c = C_1\ k\ (Pe/x)^n\ (x^n/x) = C_2\ x^{n-1}$$

and

$$\bar{h}_{c,L} = \frac{C_2}{L} \int x^{n-1}\, dx = \frac{1}{n}\, h_{c,L} \quad .$$

Then in forced convection:

sub laminar: $n = 1/3$, $\bar{h}_{c,L} = 3\, h_{c,L}$,

laminar : $n = 1/2$, $\bar{h}_{c,L} = 2\, h_{c,L}$,

turbulent : $n = 4/5$, $\bar{h}_{c,L} = (5/4)_{c,L}$.

In natural convection $Nu_x = C_1\, Ra_x^n$, hence,

$$h_c = C_1\, k\, (Ra/x^3)^n\, (x^{3n}/x) = C_2\, x^{3n-1}$$

and

$$\bar{h}_{c,L} = \frac{C_2}{L} \int x^{3n-1}\, dx = \frac{1}{3n}\, h_{c,L} \quad .$$

Average values in natural convection then become:

sub laminar: $n = 1/6$, $\bar{h}_{c,L} = 2\, h_{c,L}$,

laminar : $n = 1/4$, $\bar{h}_{c,L} = (4/3)\, h_{c,L}$,

turbulent : $n = 1/3$, $\bar{h}_{c,L} = h_{c,L}$.

5.1.4 List of Nusselt Number Relations

The following relations are given above or are in common usage for the entrance region of a tube or on a flat plate.

Forced convection, void flow:

a) turbulent : $Nu_x = 0.0296\, Re_x^{.8}\, Pr^{.33} \sim (.17\, Pe_x^{.4})^2$

$\bar{N}u_L = 0.0370\, Re_L^{.8}\, Pr^{.33} \sim (.19\, Pe_L^{.4})^2$

b) laminar : $Nu_x = 0.332\, Re_x^{.5}\, Pr^{.33} \sim (.58\, Pe_x^{.25})^2$

$\bar{N}u_L = 0.664\, Re_L\, Pr^{.33} \sim (.815\, Pe_L^{.25})^2$

c) sub-laminar : Nu_x = ?

$\bar{N}u_L$ = ?

Natural convection, void flow:

d) turbulent : Nu_x = $= 0.1\ Ra_x^{1/3}$

$\bar{N}u_L$ = $= 0.1\ Ra_L^{1/3}$

e) laminar : Nu_x = $= 0.44\ Ra_x^{1/4}$

$\bar{N}u_L$ = $= 0.59\ Ra_L^{1/4}$

f) sub-laminar : Nu_x = $= 0.63\ Ra_x^{1/6}$

$\bar{N}u_L$ = $= 1.26\ Ra_L^{1/6}$

Forced convection, porous flow:

g) turbulent : Nu_x = ?

$\bar{N}u_L$ = ?

h) laminar : $Nu_x = 0.601\ Pe_x^{1/2} = (0.775\ Pe_x^{1/4})^2$

$\bar{N}u_L = 1.202\ Pe_L^{1/2} = (1.10\ Pe_L^{1/4})^2$

i) sub-laminar : $Nu_x = 2.126\ Pe_x^{1/3} = (1.39\ Pe_x^{1/6})^2$

$\bar{N}u_L = 6.378\ Pe_L^{1/3} = (2.53\ Pe_L^{1/6})^2$

The natural convection, porous flow correlations are the ones that we seek.

5.1.5 Preliminary Estimate of Coefficients

The exponent n values for the three modes in natural convection are selected to be 1/6, 1/4 and 1/3 based on the above

results. The coefficient C values in porous flows will be estimated by a comparison with similar values in forced convection. It should be noted that the computer program uses local forced convection correlations but average natural convection relations over the wall area of a given axial segment. A comparison of C values also shows (coincidentally) that the average natural convection C values compare best with the local forced convection C values. Known C values are given in Table 5.1 in the form of $Nu = C\ Ra^n$ so that the forced convection C values are squared.

The values are estimated as follows. The local, void, forced, laminar C value is similar to the average, void, natural, laminar value (as are the corresponding turbulent values); therefore, it is assumed that the average, porous, natural, laminar C equals the local, porous, forced, laminar value of 0.78. Then the local, porous, natural, laminar C equals 0.78 divided by 4/3 or 0.59.

A comparison of the average, void, forced C values for laminar and turbulent flow gives a nearly one-to-one agreement with the corresponding forced convection values over a cylinder presented in Section 5.1.2. The average, sub-laminar C-value in Table 5.1 is then 0.99 from Section 5.1.2 and the local value is $\{(\sqrt{0.99})(1/3)\}^2 = 0.58$, where the coefficient must be returned to forced convection space for conversion.

The forced and natural C values in local, void, sub-laminar flows are similar. Assuming the same ratio for porous flows, the local, porous, natural, sub-laminar C becomes (0.63/.58) 1.39 = 1.51 with the average value becoming 3.02.

Table 5.1: Known and estimated C-values in forced convection, $Nu = (C\ Pe^n)^2$, and in natural convection, $Nu = C\ Ra^n$ for vaoid and porous flows on plates and in entrance regions. Values in parens represent estimated values.

	Local				Average			
	Void		Porous		Void		Porous	
	forced	nat.	forced	nat.	forced	nat.	forced	nat.
Sub-laminar	(0.58)*	0.63	1.39	(1.51)[3]	(0.99)[2]	1.26	2.53	(3.02)*
Laminar	0.58	0.44	0.78	(0.59)*	0.82	0.59	1.10	(0.78)[1]
Turbulent	0.17	0.10	(0.20)[5]	(0.10)[4]	0.19	0.10	(0.25)	(0.10)*

* Calculated from local-to-average relationship in Section 5.1.3. Note that forced convection values must be reduced to their equivalent value before correction and then returned to the natural convection equivalent.

[1-5]The order in which values are estimated as discussed in the text.

The "turbulent," porous C values are the most speculative. Extrapolating vertically, as well as horizontally suggests about 0.10 for the local and average, porous, natural turbulent C values. The forced, porous, turbulent C values should then be about 0.20 and 0.25 for the local and average value, respectively.

If the sub-laminar, average, porous, natural coefficient is recalculated to match the laminar correlation at the $Ra = 10^4$ range boundary, the 3.02 value becomes 1.67. The preliminary porous flow relations for calculating the average $\bar{N}u$ values are then:

$$\text{sub-laminar:} \quad \bar{N}u_L = 1.67\ Ra_L^{1/6} \quad , \qquad (5.7)$$

$$\text{laminar} \quad : \quad \bar{N}u_L = 0.78\ Ra_L^{1/4} \quad , \qquad (5.8)$$

$$\text{turbulent} \quad : \quad \bar{N}u_L = 0.10\ Ra_L^{1/3} \quad , \qquad (5.9)$$

where L represents the natural convection characteristic length, which may be the diameter of the link, the effective seam height, or a length characteristic of the terminal velocity in porous flows.

5.1.6 Field Test Determination of Pore Size

Assuming a uniform link zone porosity, the effective pore size can be estimated using D'Arcy's law and field test values. The best accuracy is obtained from stages occurring close to the RCL phase, of longer duration, and with minimum pressure drop. The last condition minimizes the effect of plugging. Reynolds number values based on the pore diameters found are much less than 5; therefore,

it appears that the D'Arcy flow assumption is valid.

D'Arcy's law in a porous cylinder can be written as [13]

$$\frac{dp}{dx} = -\lambda \frac{1}{d_p} \frac{\rho u_p^2}{2} \quad , \tag{5.10}$$

where the friction coefficient recommended by Veronese [27,13] when $Re < 5$ is

$$\lambda \simeq 1150/(Re/4) \quad . \tag{5.11}$$

The seepage velocity, u_p, is estimated from the effective volume flow rate and cross sectional area

$$u_p = \frac{\dot{V}}{A} = \frac{\rho_{a,s}}{\rho} \frac{\dot{V}_{inj}}{A} (1 + W_{ox} R_{vm/o} \rho / \rho_{vm}) \quad , \tag{5.12}$$

where it is assumed that $\rho_{vm} \simeq \rho$. The value of ρ is calculated from the ideal gas equation of state using mean link pressure and M = 24.71 which is typical of the product gas composition.

Substituting (5.11) and (5.12) into (5.10) and solving for the pore diameter, d_p gives the values shown in Table 5.2 for the low flow rate stages. The weighted average value for CLE-23 is 0.000411 ft, for CLE-12 based on direction 12 and 21 is 0.000451 ft, but for CLE-12 based on 13 and 31 the weighted average is 0.000894 ft. Similar calculation for medium flow rates (stage 12 of CLE-123) gives d_p = 0.000428 ft and for high flow rates d_p = 0.000802 ft.

Table 5.2: Effective pore diameter values

Phase	Stage	Dura. (days)	Direction	Δp (psi)	Δx (ft)	ρ (lb/ft^3)	u_b (ft/m)	d_p (ft)
CLE-23	3	0.500	32	186	44	0.330	3.56	0.000430
	7	0.625	32	246	44	0.378	3.02	0.000345
	21	1.000	23	154	44	0.273	2.80	0.000419
	22	3.875	23	165	44	0.292	2.94	0.000415
CLE-123A	2	1.750	13	189	104	0.359	2.34	0.000532
	9	4.250	31	69	104	0.289	3.74	0.001113
	10	1.250	13	106	104	0.314	2.01	0.000658
CLE-123A	5	1.375	21	86	60	0.319	1.64	0.000502
	6	3.250	12	100	60	0.273	1.33	0.000418
	8	1.875	12	102	60	0.321	1.76	0.000477
	10	0.125	12	213	60	0.367	2.27	0.000375

5.1.7 Field Test Determination of Terminal Length

The mass transfer of oxygen to the virgin coal wall is limited by either the exponential mixing or the boundary layer mass transfer. The former is influenced by the characteristic length in the u_{nc} expression and the latter by a similar or identical term in Ra (depending on the form used). Attempts to use the link zone diameter or height gave extraordinarily large mixing and mass transport near the injection region. Use of d_p as the characteristic length resulted in oxygen break through (with the model). A terminal characteristic length corresponding to a terminal velocity was then determined by matching predictions of volatile matter consumed after various stages with the values actually consumed in the field test. In this way, both the terminal length, d_{nc}, and the coefficients in the Nu expressions were determined for the low and high flow CLE phases.

Plots of predicted tons versus d_{nc} for families of C from $Nu = C\ Ra^n$ in the case of the low flows (CLE-23 and CLE-123A) showed that d_{nc} could be determined precisely ($\pm$ 2%) but that the calculation was insensitive to the C value. This indicates that mixing is controlling the oxygen transport to the wall. As a result d_{nc} = 0.0123 ft ($\pm$ 2%) and $Nu = 1.67\ Ra^{1/6}$ in this sub-laminar regime (as indicated by Ra values using D_{nc}) but the result is insensitive to C and hence the 1.67 value has not been validated.

Similar plots for the high flows of CLE-123B are less explicit in terms of d_{nc} but give more information about C. In this case, larger C values yield lower d_{nc} values as might be expected.

Neither mixing nor boundary layer transport appear to dominate. In addition, when plots after 90, 100 and 106.1 days are compared there is a systematic dip in the results which suggests varied mechanisms or systematic errors in the data reduction or measurement. Compromise values of C = .15 and d_{nc} = 0.05 ft result in probable error boxes of about $\pm$ 20%. The values are within 5% at the beginning and are within 1% at the end of CLE-123B. Our previous correlation [3] of Nu = .21 $Ra^{1/4}$ for this "laminar" regime with $d_{nc} \simeq 0.04$ gives similar but less precise results. The affected region is also larger around the injection well indicative of increased boundary layer transport.

The recommended Nu relations are then

$$\text{sub-laminar} : \quad Nu(d_{nc}) = 1.67\ Ra^{1/6} , \tag{5.13}$$

$$\text{laminar} : \quad Nu(d_{nc}) = 0.15\ Ra^{1/4} . \tag{5.14}$$

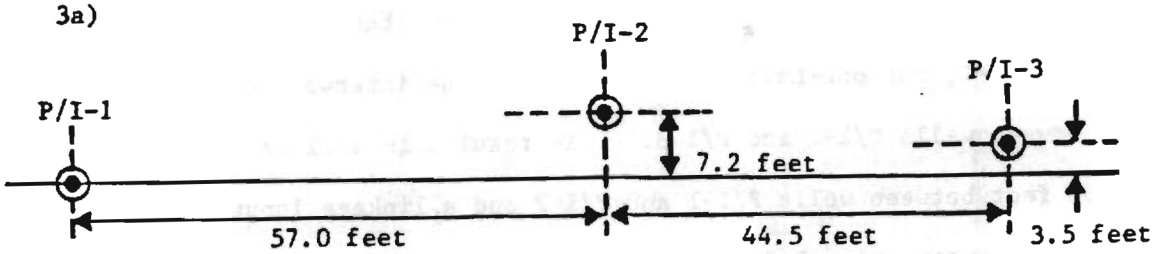
No information was obtained to obtain the C-value (or d_{nc}) for the turbulent mode relation (3.19) and (5.9).

5.2 Special CLE Modeling Features

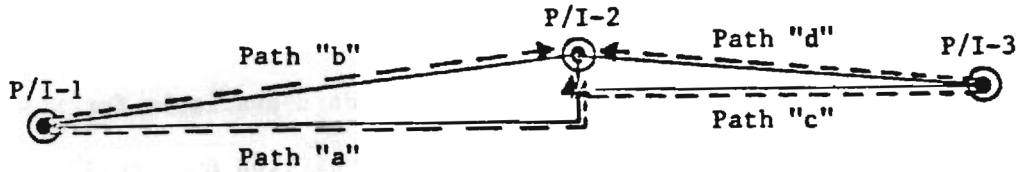
5.2.1 Modeling Multiple Wells at Pricetown I

The gasification model assumes that the P/I wells are located on the same horizontal axis. Therefore, to facilitate modeling of the CLE stages, certain modifications were made to the actual well locations. The actual subsurface well locations are as shown in Figure 3a. The exact location and length of the initial porous link created by the RCL phase is undetermined. Hence, an arbitrary linkage has been created. It is assumed that the linkage connecting wells P/I-1, P/I-2 and P/I-3 falls within the triangular regions shown in Figure 3b. From this assumption, the upper and lower limits for each well pair spacing are specified. For the well pair including P/I-1 and P/I-2, the maximum linkage length occurs if path "a" is assumed (64.2 feet) and the minimum length occurs if path "b" is assumed (57.5 feet). For the well pair including P/I-2 and P/I-3, path "c" results in the maximum linkage length (48.2 feet) and path "d" results in the minimum linkage length (44.7 feet). As can be seen in Fig. 5.2b, the vertical distance separating wells P/I-2 and P/I-3 (3.7 feet) is common to both assumed linkage paths "a" and "c". The gasification model is not capable of modeling this duplicate flow path; therefore, a scheme was adopted to circumvent the problem. After discussions with Eddy and Martin [28], it was assumed that the actual linkage path more closely followed paths "b" and "d". Hence, the vertical distance separating wells P/I-2 and P/I-3 (3.7 feet) is omitted. In addition, the vertical distance separating wells P/I-1 and P/I-3 (3.5 feet) is divided up so that

3a)



3b)



Path "a" 64.2 Ft.
Path "b" 57.5 Ft.
Path "c" 48.2 Ft.
Path "d" 44.7 Ft.

3c)

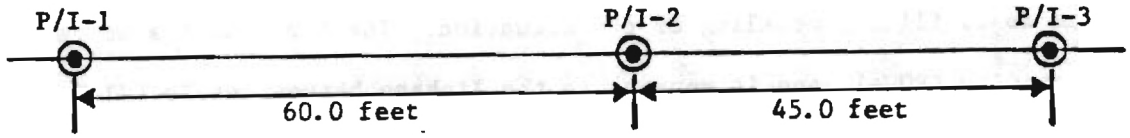


Fig. 5.2: MODIFICATIONS PERFORMED ON THE ACTUAL SUBSURFACE WELL LOCATIONS.

three feet is added to the interwell distance between wells P/I-1 and P/I-2, and one-half foot is added to the interwell distance between wells P/I-2 and P/I-3. This results in a linkage length of 60 feet between wells P/I-1 and P/I-2 and a linkage length of 45 feet between wells P/I-2 and P/I-3 (refer to Fig. 5.2c). These lengths are within the specified limits and they approximate the lengths of the assumed linkage paths "b" and "d". This approach also has the advantage of rounding off the interwell spacing to whole numbers which facilitates the development of the finite difference scheme.

This somewhat arbitrary approach is not due to a weakness of the model. It is just a reflection of the lack of data available for use in the determination of the actual linkage position and length. If more data were available about the RCL phase (namely flow rates, flow duration and direction data, product gas compositions and thermocouple measurements), then a more accurate determination of the linkage position and length could be implemented into the model.

In the actual modeling of the Pricetown I test facility, two subsystems are defined within the program. Fig. 5.3 illustrates these subsystems plus the spatial variables defined within the program to facilitate modeling of the situation. The first subsystem is denoted by KROW=1, and it represents the linkage between wells P/I-2 and P/I-3. The second subsystem is denoted by KROW=2, and it represents the linkage between wells P/I-1 and P/I-2. The spatial variables XPOS1, XPOS2, and XPOS3 represent the axial distance to wells

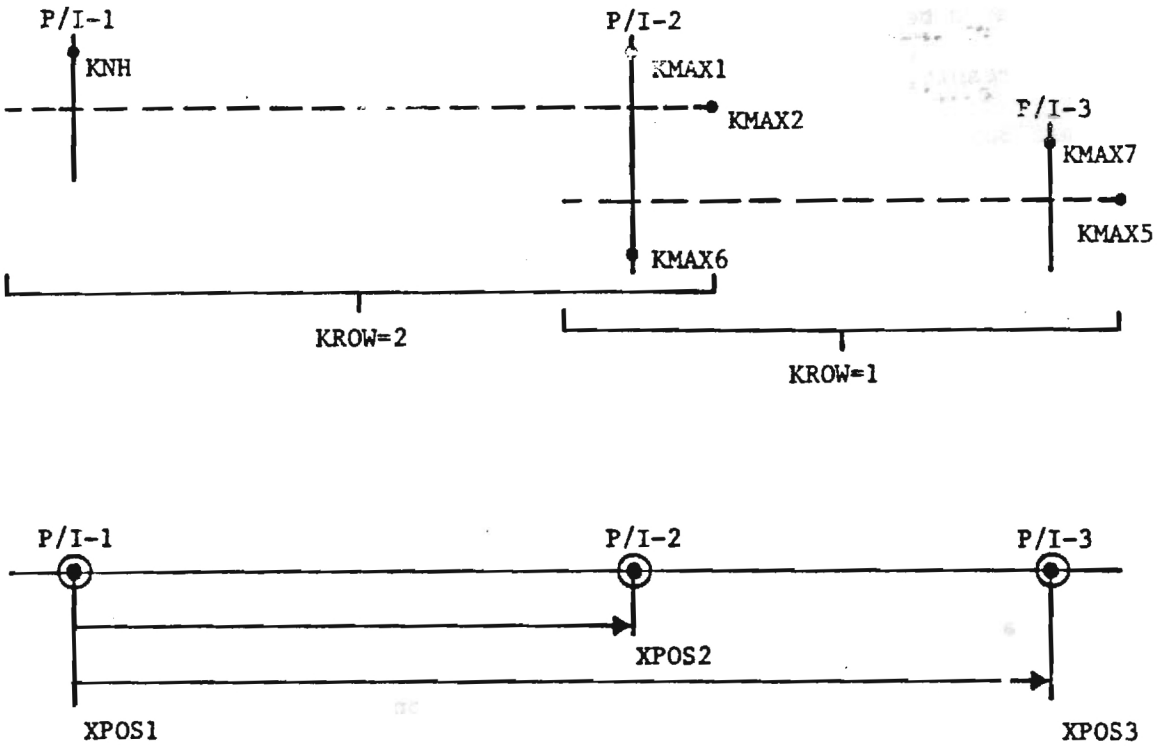


Fig. 5.3 SUBSYSTEMS AND SPATIAL VARIABLES DEFINED TO FACILITATE MODELING.

P/I-1, P/I-2, and P/I-3 respectively. Well P/I-1 is assumed to be the reference position; therefore, XPOS1=0.0. From this assumption, it follows that XPOS2=60.0 feet and XPOS3=105.0 feet.

The finite difference scheme used in the CLE model is similar to the one used in the gasification model. Each hemispherical production/injection region is divided into eight spherical sectors. As stated before, both axial and radial growth occur in this region. As a result, the region of coal affected by the CLE stages extends past both wells P/I-1 and P/I-3. In the cylindrical region, all radial distances are constant. Therefore, the number of sections contained in the cylindrical region is a function of the interwell spacing and the individual section length. The individual section length is a parameter that can be adjusted according to the accuracy desired. A shorter section length results in smaller finite difference elements and a more accurate solution. It is arbitrarily assumed that each section in the cylindrical region has an axial length of one foot. Hence, there are 60 sections in the cylindrical region between wells P/I-1 and P/I-2 and 45 sections in the cylindrical region between wells P/I-2 and P/I-3. In the program itself, these sections are denoted by the variable "K", and all other defined variables which depend on location have the subscript "K".

The computer program consists of a time loop (denoted by the index "I") with three spatial loops (denoted by the index "K") nested within it. The three spatial loops represent different regions of the link zone, namely:

1. Hemispherical injection region

2. Cylindrical region

3. Hemispherical production region

The three distinct spatial loops are created because there are different geometry and flow calculations within each region. Making up each spatial loop are the defined "K" sections which characterize each region. As shown in Fig. 5.3, certain "K" sections are defined within the program because of their added significance in the modeling scheme. They are defined as follows (with values for Price-own I given in parentheses):

KNH — Represents the last sector in the hemispherical production/injection region of well P/I-1. (KNH=8)

KMAX1 — represents the last section in the cylindrical region of the KROW=2 subsystem. (KMAX1=68)

KMAX2 — Represents the first sector in the hemispherical production/injection region of well P/I-2 when it is included in the KROW=2 subsystem. (KMAX2=76)

KMAX6 — Represents the last sector in the hemispherical production/injection region of well P/I-2 when it is included in the KROW=1 subsystem. (KMAX6=84)

KMAX7 — Represents the last section in the cylindrical region of the KROW=1 subsystem. (KMAX7=129)

KMAX5 — Represents the first sector in the hemispherical production/injection region of well P/I-3. (KMAX5=137)

Each of these "K" sections (or sectors) represents either an initial or final section (or sector) of one of the above-mentioned regions. Their values are determined from the physical layout of the P/I wells and are entered into the program. Within the program, these variables are used as limits for the three spatial loops. In this way the model is made more general (e.g. is able to handle different interwell

spacings). During each time step, calculations are performed on each "K" section of the three loops. The time step (program variable: DELTAT) is a parameter that can be adjusted according to the accuracy desired. A shorter time step results in a more accurate representation of the actual process. The trade-off involved is that a shorter time step requires longer overall execution time. In the program a time step of half a day is used.

5.2.2 Modeling the Production Well Region

The gasification model does not consider any type of production well geometry. To accurately model the CLE stages of the Pricetown I field test, some sort of production well geometry must be considered. A production well region similar to the gasification model's injection well region was devised. The relations determining the geometry of the hemispherical production well region are identical to those used for the hemispherical injection well region of the gasification model. The region is divided into eight spherical sectors and the flow of products from each sector is dependent upon the angle characterizing each sector.

It is assumed that the product gases are removed uniformly from the production well region. Therefore, half the total flow is removed in the cylindrical side of the production region, and the hemispherical side is responsible for removing the rest. Applying the conservation of mass principle to a conical sector results in the expression:

$$\dot{m}_{b,L,k}\, dt = [\dot{m}_{b,L,k-1} + \dot{m}_{vm,k} - \dot{m}_{p,R,k}]\, dt.$$

Where, for each time step, the mass flow rate of the blast in the lateral direction (parallel to the link/coal interface) leaving the sector in question, $\dot{m}_{b,L,k}$, is equal to the mass flow rate of the blast in the lateral direction leaving the upstream sector, $\dot{m}_{b,L,k-1}$, plus the volatile matter removed from the virgin coal in

the sector, $\dot{m}_{vm,k}$, minus the product gases removed in the radial direction from the sector, $\dot{m}_{p,R,k}$. (Refer to Fig. 5.4) The volatile matter removed from the sector is calculated from the expression:

$$\dot{m}_{vm,k}\, dt = R_{vm/o}\, \dot{m}_{O,w,k}\, dt.$$

The mass flow rate of oxygen to the link/coal interface for the sector being considered, $\dot{m}_{O,w,k}$, is calculated from the expression

$$\dot{m}_{O,w,k}\, dt = [\dot{m}_{O,L,k-1} - \dot{m}_{O,L,k}]\, dt,$$

where $\dot{m}_{O,L,k-1}$ represents the mass flow rate of oxygen in the lateral direction leaving the upstream sector, and $\dot{m}_{O,L,k}$ represents the mass flow rate of oxygen in the lateral direction leaving the sector in question. The equation used for obtaining $\dot{m}_{O,L,k}$ is:

$$\dot{m}_{O,L,k}\, dt = (\dot{m}_{O,L,k-1}\, dt)\, \exp\left[\frac{-h_m \rho_b \frac{\partial A_w}{\partial x}\,(x_k - x_{k-1})}{\dot{m}_{b,L,k-1}}\right].$$

This equation takes into account the previously mentioned restrictions on the oxygen availability within the linkage.

The mass flow rate of products removed in the radial direction from the sector, $\dot{m}_{p,R,k}$, is expressed as

$$\dot{m}_{p,R,k}\, dt = \dot{m}_{p,T,k}\, dt\, [\cos(\alpha_{N_{k-1}}) - \cos(\alpha_{N_k})],$$

where α_{N_k} is the angle which characterizes the "K" sector (refer to

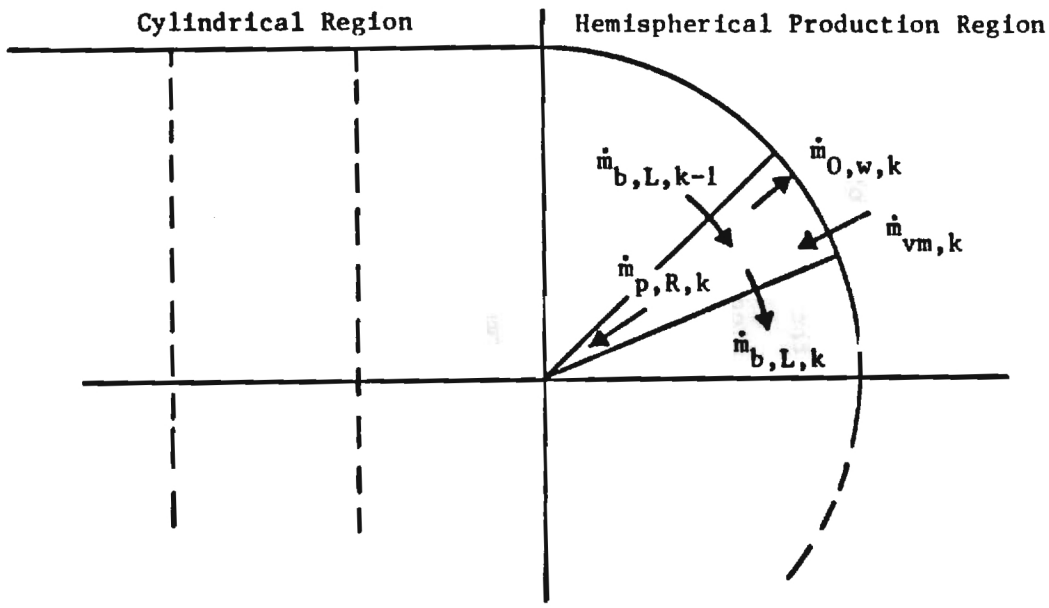


Fig. 5.4: HEMISPHERICAL PRODUCTION REGION - SPHERICAL SECTOR MASS BALANCE.

Fig. 5.5), and $\dot{m}_{p,T,k}$ represents the total mass flow rate of the products that are removed by the hemispherical side of the production well region. The equation used for calculating $\dot{m}_{p,T,k}$ is:

$$\dot{m}_{p,T,k}\, dt = [\dot{m}_{p,T,k-1} + \dot{m}_{vm,k}]\, dt.$$

The mass balance takes into account the possibility of volatile matter being removed from the coal surrounding the hemispherical production region. As with the hemispherical injection region, each individual sector grows radially as the coal is affected. This effect is minimal because of the low oxygen concentration of the blast in the vicinity of the production well. A flow chart of the hemispherical production well calculations performed by the computer program is presented in Fig. 5.6.

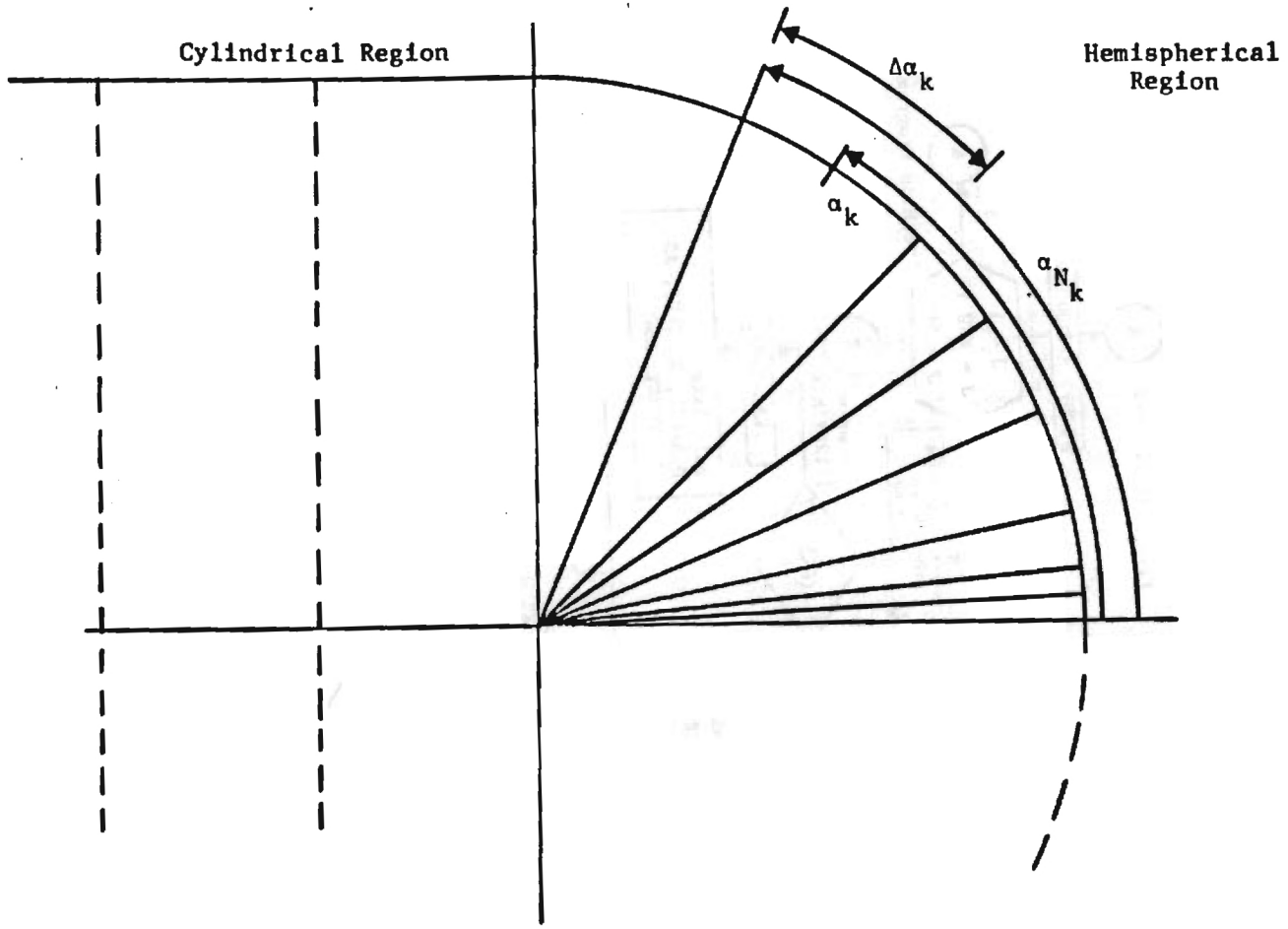


Fig. 5.5: CONVENTIONAL HEMISPHERICAL PRODUCTION/INJECTION WELL REGION.

Fig. 5.6: HEMISPHERICAL PRODUCTION WELL CALCULATIONS - FLOW DIAGRAM

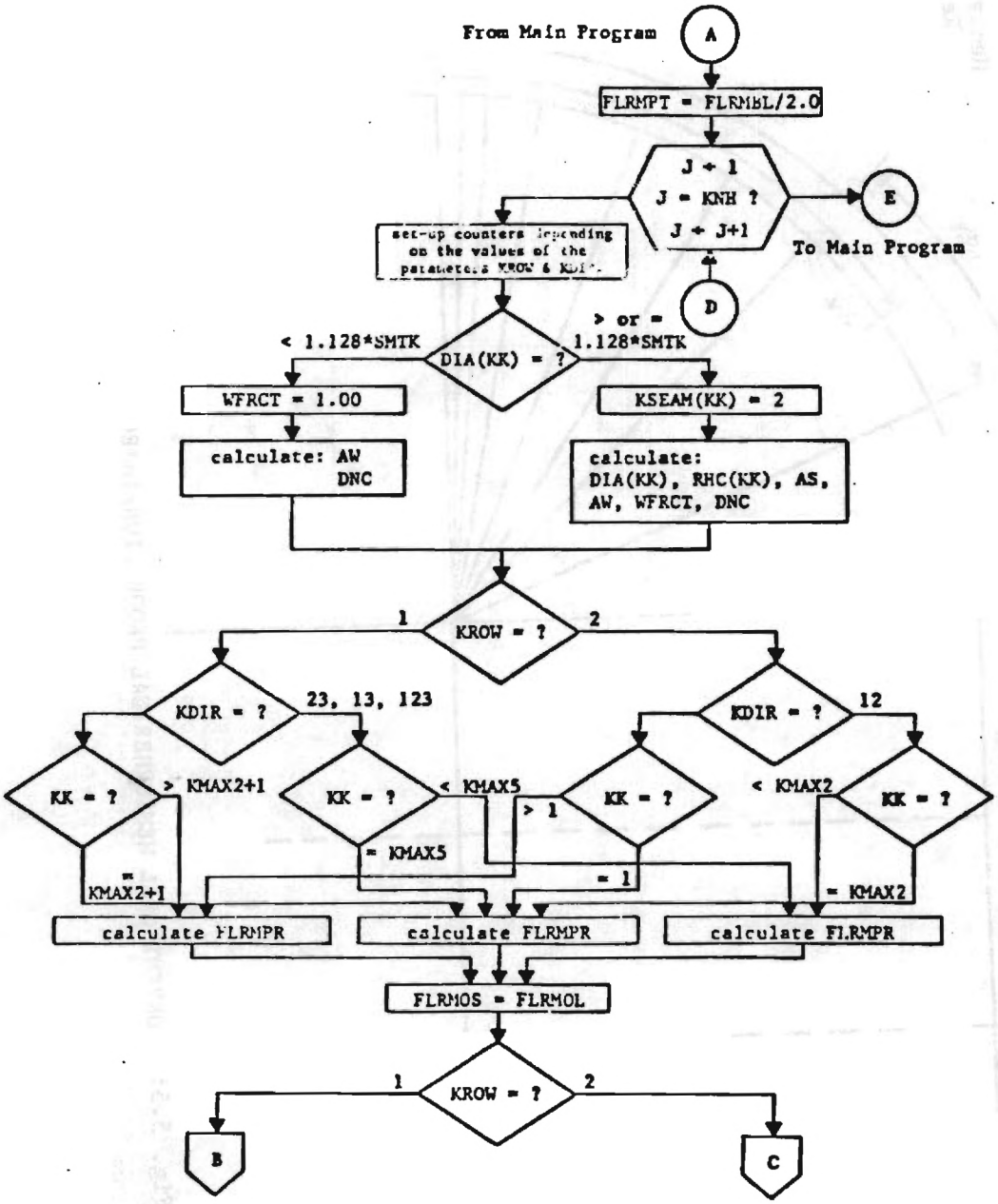
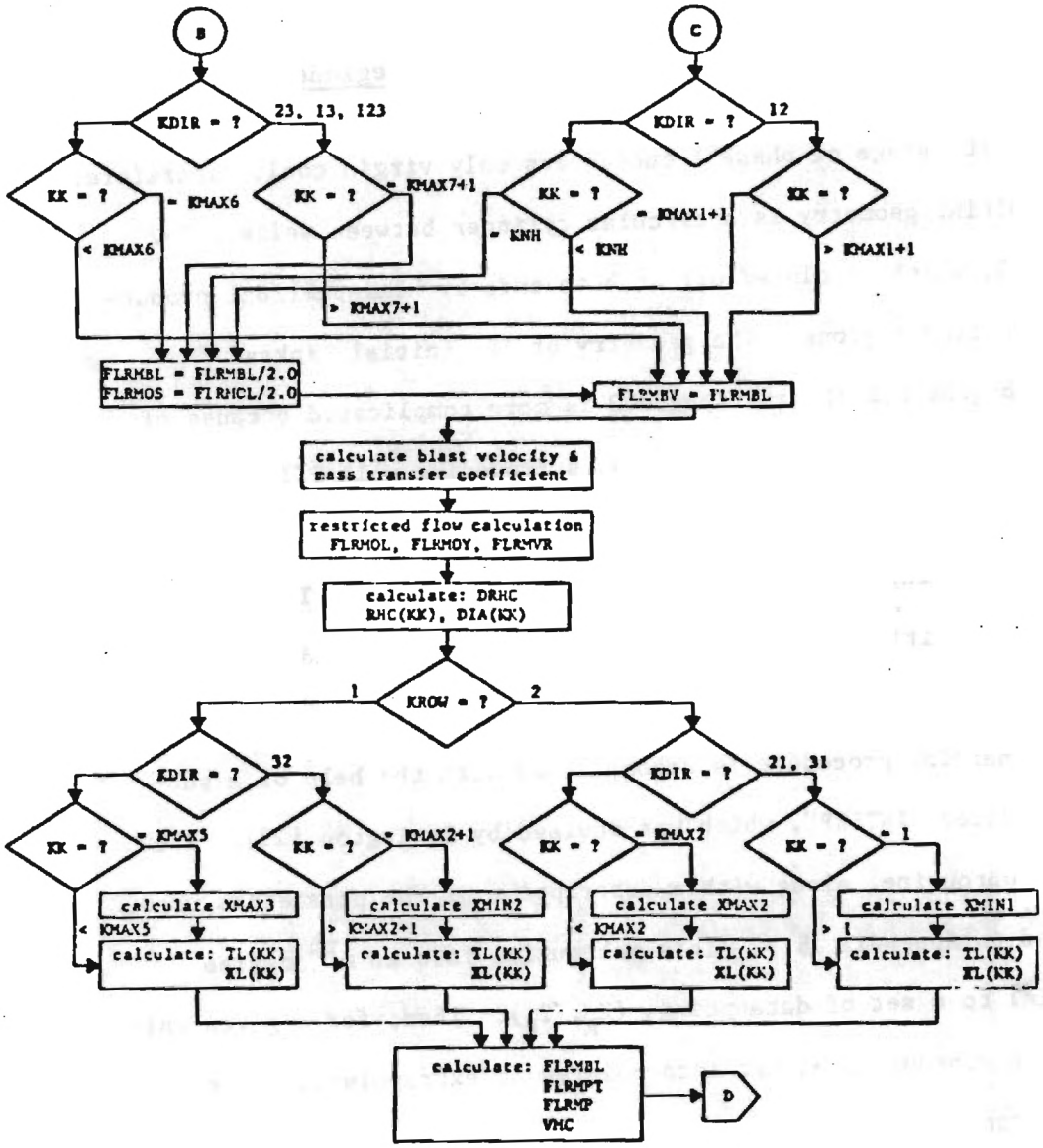


Fig. 5.6: (CONT.)


B
KDIR = ?
23, 13, 123
KK = ?
= KMAX6
< KMAX6
KK = ?
= KMAX7+1
> KMAX7+1
C
KDIR = ?
12
KK = ?
= KMAX1+1
< KNH
= KNH
KK = ?
> KMAX1+1
FLRMBL = FLRMBL/2.0
FLRMOS = FLRMCL/2.0
FLRMBV = FLRMBL
calculate blast velocity & mass transfer coefficient
restricted flow calculation FLRMOL, FLRMOY, FLRMVR
calculate: DRHC RHC(KK), DIA(KK)
KROW = ?
1
2
KDIR = ?
32
KK = ?
= KMAX5
< KMAX5
calculate XMAX3
calculate: TL(KK) XL(KK)
KK = ?
= KMAX2+1
> KMAX2+1
calculate XMIN2
calculate: TL(KK) XL(KK)
KDIR = ?
21, 31
KK = ?
= KMAX2
< KMAX2
calculate XMAX2
calculate: TL(KK) XL(KK)
KK = ?
= 1
> 1
calculate XMIN1
calculate: TL(KK) XL(KK)
calculate: FLRMBL FLRMPT FLRMP VMC
D

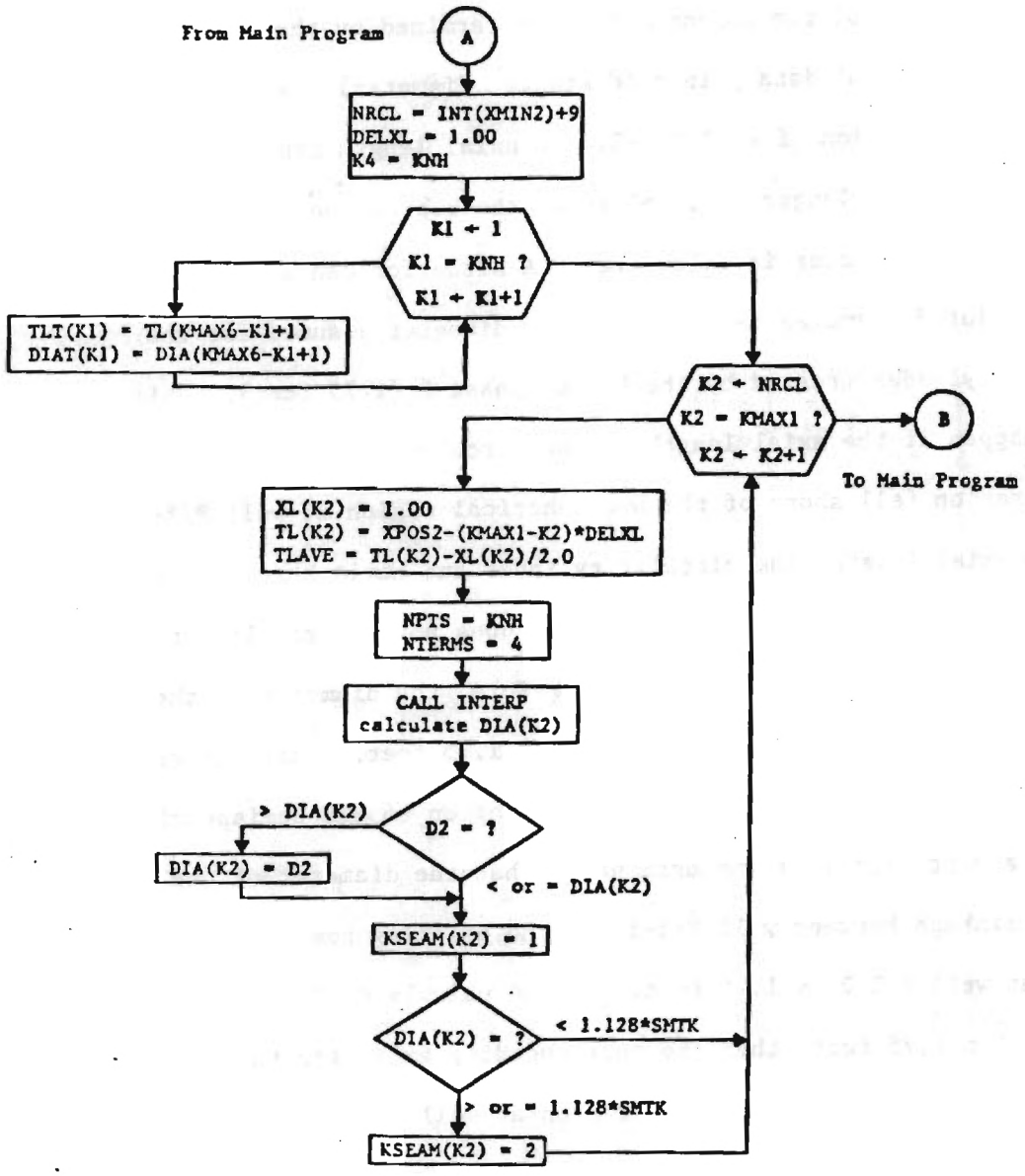
5.2.3 Merging Cylindrical with Hemispherical Regions

The RCL stage of phase 1 encounters only virgin coal. Therefore, the resulting geometry is a circular cylinder between wells P/I-2 and P/I-3, which is closed off at both ends by hemispherical production/injection regions. The geometry of the initial linkage created by the RCL stage of phase 2 is more complicated because of the existing region of affected coal surrounding well P/I-2. As a result, the circular cylinder created by the RCL of phase 2 is merged with the existing hemispherical region at well P/I-2. This leads to a smooth transition between the regions of coal affected by phases 1 and 2.

The merging procedure is accomplished with the help of a subroutine called "INTERP", which was devised by Bevington [21]. The FORTRAN subroutine, along with a description of the parameters used, is listed in Appendix 5.7. This subroutine fits an n^{th} degree polynomial to a set of data points (X_k, Y_k). Then, for a given value of X_k, the subroutine either interpolates or extrapolates for the corresponding value of Y_k.

A flow diagram of the calculations performed by the computer program during the merging of the cylindrical region with the hemispherical region is presented in Figure 5.7. In general, the first step is to label an initial axial length (measured from well P/I-1) of the circular cylinder created by the RCL of phase 2. From this location on, the diameter of each "K" section located in the KROW=2 subsystem is determined by the subroutine "INTERP". A

Fig. 5.7: CALCULATIONS PERFORMED DURING THE MERGE OF THE CYLINDRICAL REGION WITH THE HEMISPHERICAL REGION - FLOW DIAGRAM



third degree polynomial is used to develop a relationship between the diameter of the hemispherical region of affected coal located at well P/I-2 and the corresponding axial distance from well P/I-1. The coefficients of the polynomial are determined by the subroutine from a set of eight data points (distance, diameter) taken from the hemispherical region of well P/I-2. An axial length greater than the initial axial length is supplied to the subroutine, and a corresponding diameter is calculated. A situation can arise where the calculated diameter is less than the diameter assumed for the circular cylinder created by the RCL of phase 2 (1.75 feet). This would happen if the axial length of the circular cylinder under consideration fell short of the hemispherical region at well P/I-2. At this axial length, the circular cylinder and hemisphere have not intersected, and the calculated diameter does not accurately represent the diameter of the linkage. Therefore, the diameter of the linkage at this point is assumed to equal 1.75 feet. This ensures a smooth transition from the cylindrical region to the hemispherical region, and it satisfies the assumption that the diameter of the initial linkage between well P/I-1 and the existing hemispherical region at well P/I-2 is 1.75 feet. If the calculated diameter is greater than 1.75 feet, then the corresponding axial length falls within the existing hemispherical region at well P/I-2, and the calculated value of the diameter accurately reflects the linkage diameter. The axial length is then increased and a new diameter is calculated. This procedure continues until the cylindrical section merges with the existing hemispherical section at well P/I-2.

5.2.4 Merging Hemispherical with Cylindrical Regions

Another difficulty arose during phase 2 when well P/I-2 was used as either a production or injection well in the KROW=2 subsystem. There is already a region of affected coal surrounding well P/I-2 which is the result of phase 1 and the initial stages of phase 2. Due to the increased permeability of this region of affected coal, the oxygen in the blast diffuses through the affected region to the virgin coal and reacts at the link/coal interface. Therefore, a conventional hemispherical injection region is not formed at well P/I-2 during phase 2. Instead, there is a merging between the hemispherical injection region of well P/I-2 and the existing cylindrical region of affected coal, which is the result of phase 1.

Fig. 5.5 illustrates the conventional hemispherical production/injection region used in the program. Due to the symmetry of the region only one quadrant is shown. The region is divided into eight spherical sectors. Associated with each sector are three angles:

α_k - represents the mean angle for the "K" sector.

α_{N_k} - represents the maximum angle for the "K" sector.

$\Delta\alpha_k$ - represents the change in α_{N_k} (e.g. $\Delta\alpha_k = \alpha_{N_k} - \alpha_{N_{k-1}}$) for the "K" sector.

For the conventional hemispherical region, the values of the angles are entered into the program. Table IV lists the particular values used in the CLE model. The sectors listed in Table 5.3 are not all "equal" (e.g. equal $\Delta\alpha_k$'s). In general, the sector size increases with increasing α_k. This is done to minimize the detrimental effects

Table 5.3: Values of α, α_N, and $\Delta\alpha$ for the eight sectors contained in the hemispherical portion of the production/injection region.

Sector	α	α_N	$\Delta\alpha$
1	$\frac{1}{64}\frac{\pi}{2}$	$\frac{1}{32}\frac{\pi}{2}$	$\frac{1}{32}\frac{\pi}{2}$
2	$\frac{3}{64}\frac{\pi}{2}$	$\frac{1}{32}\frac{\pi}{2}$	$\frac{1}{16}\frac{\pi}{2}$
3	$\frac{3}{32}\frac{\pi}{2}$	$\frac{1}{16}\frac{\pi}{2}$	$\frac{1}{8}\frac{\pi}{2}$
4	$\frac{3}{16}\frac{\pi}{2}$	$\frac{1}{8}\frac{\pi}{2}$	$\frac{1}{4}\frac{\pi}{2}$
5	$\frac{5}{16}\frac{\pi}{2}$	$\frac{1}{8}\frac{\pi}{2}$	$\frac{3}{8}\frac{\pi}{2}$
6	$\frac{7}{16}\frac{\pi}{2}$	$\frac{1}{8}\frac{\pi}{2}$	$\frac{1}{2}\frac{\pi}{2}$
7	$\frac{5}{8}\frac{\pi}{2}$	$\frac{1}{4}\frac{\pi}{2}$	$\frac{3}{4}\frac{\pi}{2}$
8	$\frac{7}{8}\frac{\pi}{2}$	$\frac{1}{4}\frac{\pi}{2}$	$1\frac{\pi}{2}$

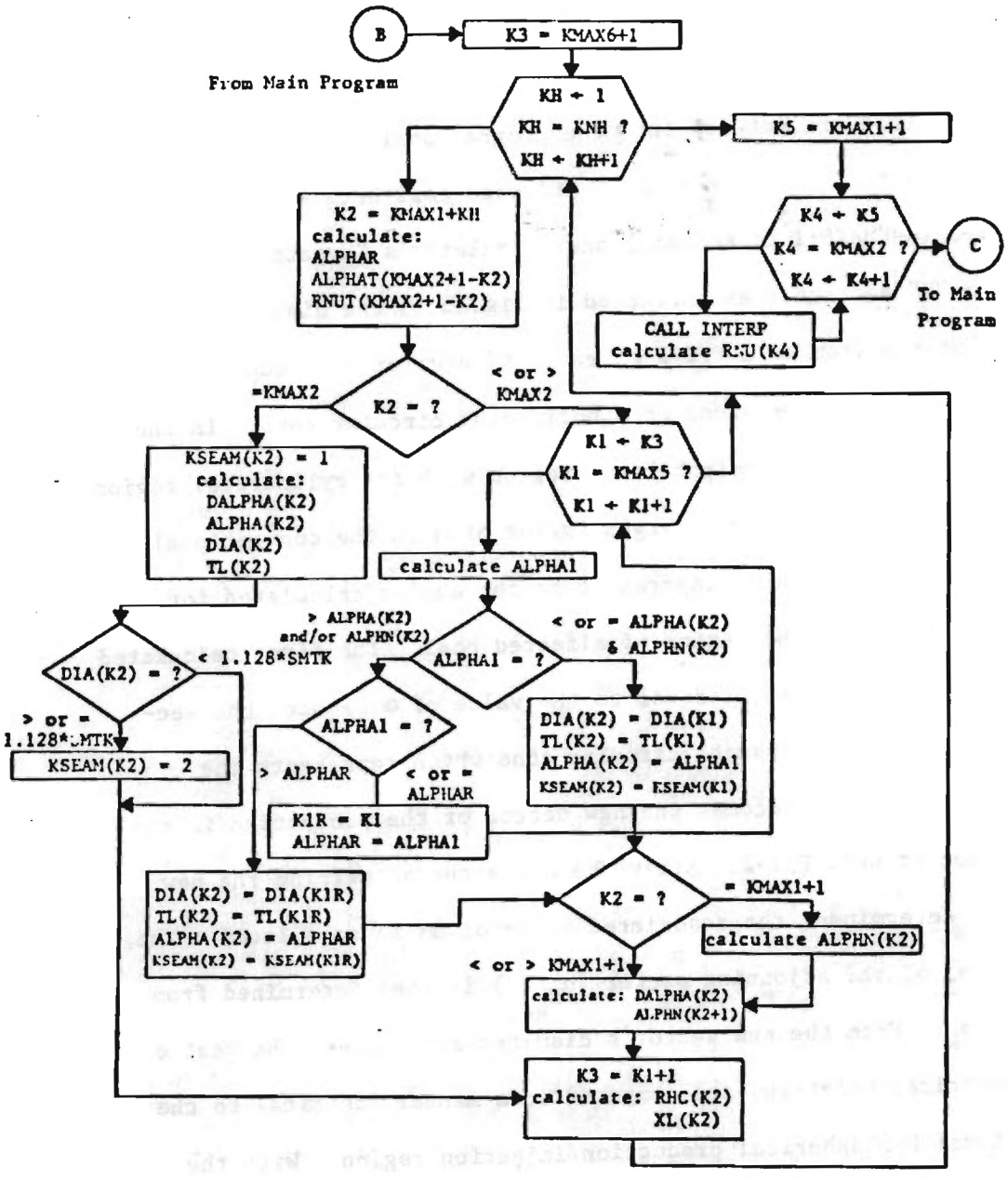
of the large discontinuities that occur in the first few conical sectors of the finite difference scheme.

The geometry of the modified production/injection region at well P/I-2 also consists of eight spherical sectors of unequal angles. This region is "tuned" to fit the existing region of affected coal connecting wells P/I-2 and P/I-3 (KROW=1 subsystem) by adjusting the value of α for each sector. A scheme was developed in which the

angle, α, became a function of the diameter and axial length from well P/I-2, which corresponded to an arbitrary section within the existing cylindrical region. A flow diagram of the calculations performed by the computer program during the merging of the hemispherical region with the cylindrical region is presented in Figure 5.8.

During phase 2, the program initially assumes a conventional hemispherical production/injection region at well P/I-2. Therefore, the angles that are entered into the program apply. The program then marches through the region of affected coal between wells P/I-2 and P/I-3 (K=KMAX6+1 to K=KMAX5) and calculates a "hypothetical" angle for each "K" section. As reflected in Fig. 5.9, the diameter and axial distance from well P/I-2 of each "K" section is assumed to correspond to the dimensions of a horizontal circular cone. In the actual merging of the hemispherical region with the cylindrical region, the program starts with the largest value of α in the conventional hemispherical region and compares it to the angles calculated for the sections within the region of affected coal. The first calculated angle that is less than or equal to the value of α becomes the sector's new α. The horizontal circular cone which represents the selected "K" section becomes the new sector of the production/injection region of well P/I-2. After the angle characterizing the new sector is determined, the associated value of $\Delta\alpha$ is calculated. The value of α_N of the adjoining sector ($\alpha_{N_{k-1}}$) is then determined from α_{N_k} and $\Delta\alpha_k$. From the new sector's diameter and angles, the rest of the geometrical relations are computed in a manner identical to the conventional hemispherical production/injection region. With the

Fig. 5.8: CALCULATIONS PERFORMED DURING THE MERGE OF THE HEMISPHERICAL REGION WITH THE CYLINDRICAL REGION - FLOW DIAGRAM



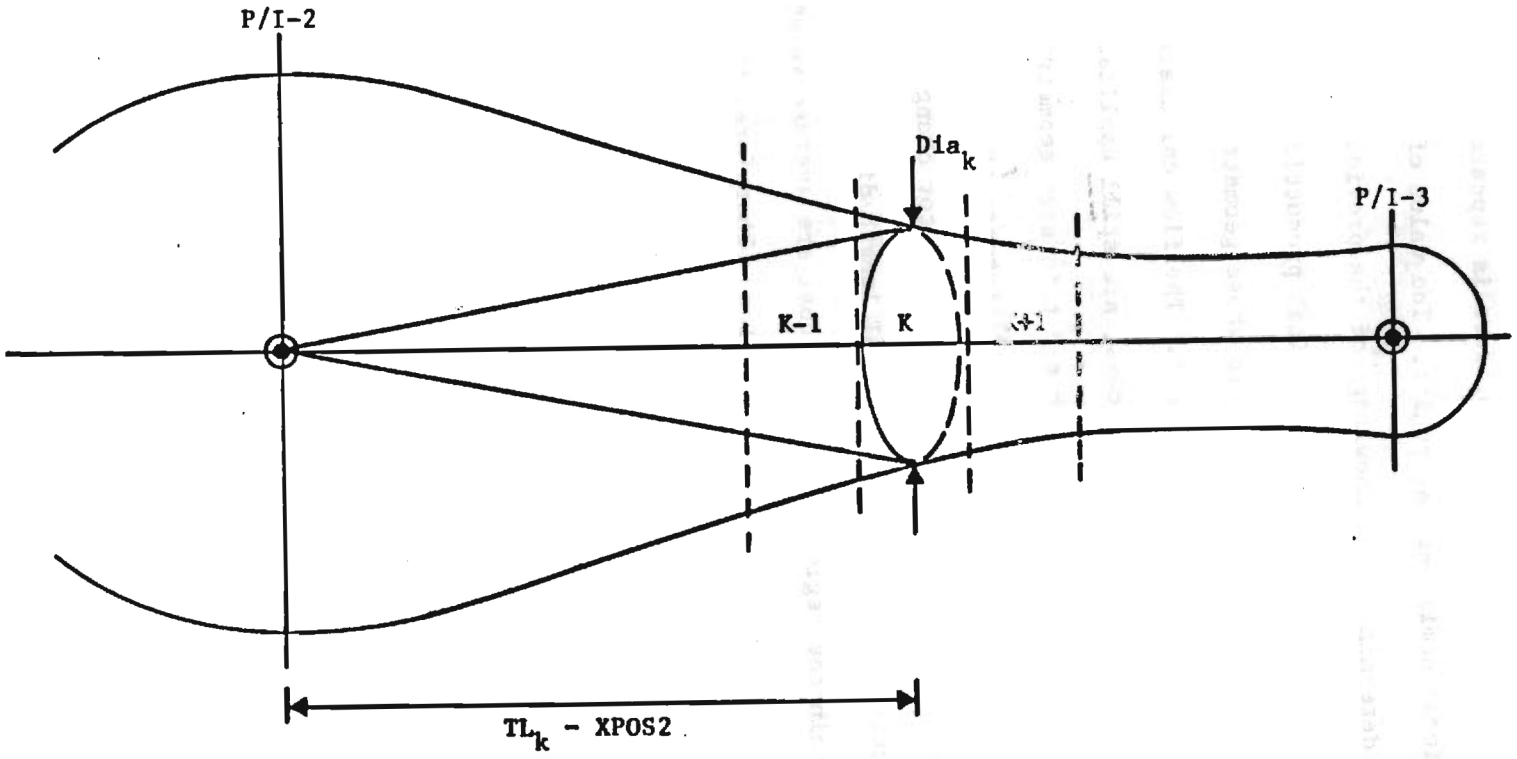


Fig. 5.9: HORIZONTAL CIRCULAR CONE REPRESENTING A SECTOR CONTAINED IN THE PSEUDO-HEMISPHERICAL PORTION OF THE PRODUCTION/INJECTION REGION AT WELL P/I-2.

exception of the last sector, this procedure is repeated for each α of the conventional hemispherical region. The value of α for the last sector is determined from knowledge of the previous sector's angles. The result is a pseudo-hemispherical production/injection region that is comprised of eight sectors whose geometry conforms with the existing region of affected coal. The flow calculations, both in the production and injection modes, are still applicable as are the provisions to handle both thick and thin seam geometries.

Due to the limitations of the finite difference approach used in the model, the characteristic angle of each sector changes during the merging process. The diameter and axial length dimensions of each section within the region of affected coal are average values and apply only to the midpoint of each section. Therefore, the data points involved are spaced one foot apart. The only way that the angle can remain constant during the process is if it corresponds to one of the existing data points. To account for this restriction, the first calculated angle less than or equal to the reference angle of a particular sector is selected. This does not lead to any difficulties in the subsequent calculations because the model is general enough to be able to handle a hemispherical production/injection region consisting of any size conical sectors.

5.3 Nomenclature for Data Input Programs

The nomenclature below is for computer programs CLEAVG and FGAVG which calculate and tabulate the property values needed as input to the CLE and FG computer programs. The computer symbols, text symbols and description are given. The variables are presented in alphabetical order. Note that m/100 m DPG indicates moles per 100 moles of dry product gas.

FORTRAN	Text	Description (units)
A	-	intermediate variable
AA(I)	a	coal consumed (m/100 m DPG)
AL(I)	ℓ	char not consumed (m/100 m DPG)
ALOST(I)	-	air lost (m/100 m DPG)
AM(I)	m	volatile matternot consumed (m/100 m DPG)
CL1	C_1	equals d + e + f
CL2	C_2	equals $4f + 2h_1 + 2_i$
CL3	C_3	equals d + 2e + 2k - 2b
DATE(I)	-	Julian date from January 1, 1979
DAYS(I)	t	duration of stage in days
DIVM(I)	a-m	volatile matter consumed
DJD(I)	-	starting time of stage (Julian date)
DRCH(I)	-	intermediate variable
FVMRM(I)	$F_{vm,R}$	percentage of volatile matter reacting
I	-	stage index
K	-	phase counter
KDIR	-	flow direction

FORTRAN	Text	Description (units)
L	-	indicates phase wells involved
M	-	counter, equals N-1
N	-	number of stages
PINJ(I)	P_{inj}	injection well pressure
P1(I)	-	P/I-1 well pressure (psia)
P2(I)	-	P/I-2 well pressure (psia)
P3(I)	-	P/I-3 well pressure (psia)
RAT(I)	CO/CO_2	molar ratio of CO to CO_2 in DPG
RCH(I)	$R_{C/H}$	mass ratio of carbon to hydrogen
RDAYS(I)	Δt	rounded duration of stage in days
RDJD(I)	-	rounded starting time of stage (Julian date)
RVMC(I)	$R_{vm/o\|cons}$	mass ratio of volatile matter to oxygen consumed
RVMD(I)	$R_{vm/o\|supl}$	mass ratio of volatile matter to oxygen supplied
TIME(I)	-	starting hour of stage during the day
VIN(I)	$\dot{V}_{inj}$	injection standard volumetric flow rate (SCFM)
VM	Y_{vm}	proximate analysis for volatile matter
VOUT(I)	$\dot{V}_{prod}$	production standard volumetric flow rate (SCFM)
W	w	equals $Y_{C,vm}/M_C$
X	x	equals Y_C/M_C
XAR(I)	x_A	percentage of argon in DPG
XCHAR	-	equals $Y_{C,FC}/M_C$
XCH4(I)	x_{CH4}	percentage of methane in DPG
XCO(I)	x_{CO}	percentage of CO in DPG
XCO2(I)	x_{CO2}	percentage of CO_2 in DPG

FORTRAN	Text	Description (units)
XH2(I)	x_{H2}	percentage of H_2 in DPG
XH2S(I)	x_{H2S}	percentage of H_2S in DPG
XLOST(I)	-	percentage of injection air lost (Eqn. 2.5)
XN2(I)	x_{N2}	percentage of N_2 in DPG
XO2(I)	x_{O2}	percentage of O_2 in DPG
Y	y	equals Y_H/M_H
Z	z	equals Y_{ox}/M_{ox}

5.4 Linking Data Input Program: CLEAVG

```
      PROGRAM CLEAVG (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     THIS IS THE LINK DATA AVERAGING PROG., UPDATED FROM CLE12
      DIMENSION VIN(60),VOUT(60),XH2(60),XN2(60),FVMRM(60),
     1XCH4(60),XCO(60),XO2(60),XH2S(60),XAR(60),XCO2(60),
     1 ALOST(60),XLOST(60),CL1(60),CL2(60),CL3(60),AA(60),AM(60),
     1AL(60),RCOC(60),RCOS(60),RVMC(60),RVMS(60),RAT(60),
     1RCH(60),P1(60),P2(60),P3(60),DATE(60),TIME(60),DAYS(60),
     1DJD(60),KDIR(60),DIVM(60),DRCH(60),RDAYS(60),RDJD(60),PINJ(60)
      READ(5,5)N
    5 FORMAT(I5)
      X=.08005
      Y=.0482
      Z=.0032719
      W=.01888
      VM=.3908
      XCHAR=.04037
      READ(5,*) (DATE(I),I=1,N),(TIME(I),I=1,N),(DAYS(I),I=1,N),
     1(KDIR(I),I=1,N),(VIN(I),I=1,N),(VOUT(I),I=1,N),
     1(P1(I),I=1,N),(P2(I),I=1,N),(P3(I),I=1,N),(XH2(I),I=1,N),
     1(XN2(I),I=1,N),(XCH4(I),I=1,N),(XCO(I),I=1,N),
     1(XO2(I),I=1,N),(XH2S(I),I=1,N),(XAR(I),I=1,N),
     1(XCO2(I),I=1,N),(RDAYS(I),I=1,N),(PINJ(I),I=1,N)
      A=(2*Z-Y)*(X-W)
      M=N-1
      DJD(1)=204.52
      DO 10 I=1,M
   10 DJD(I+1)=DJD(I)+DAYS(I)
      RDJD(1)=204.500
      DO 11 I=1,M
   11 RDJD(I+1)=RDJD(I)+RDAYS(I)
      DO 20 I=1,N
      CL1(I)=XCO(I)+XCO2(I)+XCH4(I)
      CL2(I)=4*XCH4(I)+2*XH2S(I)+2*XH2(I)
      CL3(I)=XCO(I)+2*XCO2(I)+2*XO2(I)-
     1(XN2(I)*2/3.719)
      XLOST(I)=(VIN(I)*78.084/(VOUT(I)*XN2(I))-1)*100.
      ALOST(I)=XLOST(I)*4.762*XN2(I)/3.719/100.
      DIVM(I)=CL1(I)/W
      AL(I)=CL3(I)-DIVM(I)*Z
      RVMC(I)=DIVM(I)*VM/(XN2(I)*8.6044)
      RVMS(I)=RVMC(I)*XN2(I)/(XN2(I)+XLOST(I))
      RAT(I)=XCO(I)/XCO2(I)
      RCH(I)=(XCO(I)+XCO2(I)+XCH4(I))*12/(4*XCH4(I)
     1+2*XH2S(I)+2*XH2(I)-2*AL(I))
      DRCH(I)=1-(RCH(I)*Y/(12*W))
```

```
201 AM(I)=DIVM(I)*DRCH(I)/(1-DRCH(I))
    AM(I)=AM(I)*X
    AA(I)=DIVM(I)+AM(I)
    AA(I)=AA(I)*X
 20 FVMRM(I)=(DIVM(I)/AA(I))*100
    K=3
    L=12
    WRITE(6,100) K,L
100  FORMAT("1",4X,7H PHASE ,I1,29H COMBUSTION LINK ENHANCEMENT ,I2,
   115H AT PRICETOWN I,//)
    WRITE(6,101)
    DO 21 I=1,N
 21  WRITE(6,102) I,DJD(I),DAYS(I),RDJD(I),RDAYS(I),TIME(I),
   1KDIR(I),VIN(I),VOUT(I),P1(I),P2(I),P3(I)
101  FORMAT(1H0,2X,"STAGE",3X,"INITIAL",3X,"INITIAL",3X,"ROUNDED",3X
   1,"ROUNDED",3X,"TIME",3X," FLOW ",5X,"SCFM",7X,"SCFM",8X,
   1"P/I-1",8X,"P/I-2",8X,"P/I-3",/,
   113X,"JD",6X,"DURATION",5X,"JD",5X,"DURATION",3X,"(HRS)",2X," DIR",
   18X,"IN",8X,"OUT",22X,"(PSIA)",//)
102  FORMAT(4X,I2,5X,F7.3,1X,F7.3,5X,F7.3,2X,F7.3,4X,F5.2,
   14X,I3,4X,F8.3,3X,F8.3,6X,3(F7.3,6X),/)
    WRITE(6,103)
    DO 22 I=1,N
 22  WRITE(6,104) I,RDJD(I),RDAYS(I),XH2(I),XN2(I),XCH4(I),
   1XCO(I),XO2(I),XH2S(I),XAR(I),XCO2(I)
103  FORMAT("1",2X,"STAGE",3X,"ROUNDED",3X,"ROUNDED",3X,"  H2 ",
   16X,"  N2 ",6X," CH4 ",6X,"  CO ",6X,"  O2 ",6X," H2S ",
   16X,"  AR ",6X," CO2 ",/,
   113X,"JD",6X,"DURATION",//)
104  FORMAT(4X,I2,5X,2(F7.3,3X),8(F5.2,6X),/)
    WRITE(6,105)
    DO 23 I=1,N
 23  WRITE(6,106) I,RDJD(I),RDAYS(I),AA(I),AL(I),AM(I),XLOST(I),
   1FVMRM(I),RVMC(I),RAT(I),RCH(I)
105  FORMAT("1",2X,"STAGE",3X,"ROUNDED",3X,"ROUNDED",5X,"COAL",
   16X,"NET H2O",5X," VOL MAT",4X,"PER CENT",4X,"PER CENT",
   15X,"R(VM/O)",5X," CO/CO2",6X," R(C/H)",/,
   113X,"JD",6X,"DURATION",3X,"AFFECT",5X,"REACT",6X,"REACT",5X,
   1 "AIR LOST",4X,"VOL MAT",/,
   179X,"REMOVED",//)
106  FORMAT(4X,I2,5X,2(F7.3,3X),8(F8.3,4X),/)
    STOP
    END
```

5.5 Gasification Data Input Program: FGAVG

```
      PROGRAM FGAVG (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     FOR. GAS. PROG. UPDATED FROM FWDG (12/29/82)
      DIMENSION VIN(12),VOUT(12),P1(12),P2(12),P3(12),XH2(12),XN2(12),
     1XCH4(12),XCO(12),XO2(12),XH2S(12),XAR(12),XCO2(12),XLOST(12),
     2CG1(12),CG2(12),CG3(12),AA(12),ACG(12),AL(12),RCOC(12),RCOS(12),
     3RVMC(12),RVMS(12),GAMA(12),RAT(12),RCH(12),DAYS(12),DURA(12),
     1DATE(12),TIME(12),DJD(12),KDIR(12),DJDR(12),PCRM(12),ALOST(12)
      READ(5,5)N
    5 FORMAT(I5)
      X=.06005
      Y=.0482
      Z=.00327
      READ(5,*) (DATE(I),I=1,N),(TIME(I),I=1,N),(DAYS(I),I=1,N),
     1(KDIR(I),I=1,N),(VIN(I),I=1,N),(VOUT(I),I=1,N),
     1(P1(I),I=1,N),(P2(I),I=1,N),(P3(I),I=1,N),(XH2(I),I=1,N),
     1(XN2(I),I=1,N),(XCH4(I),I=1,N),(XCO(I),I=1,N),
     1(XO2(I),I=1,N),(XH2S(I),I=1,N),(XAR(I),I=1,N),
     1(XCO2(I),I=1,N),(DURA(I),I=1,N)
      B=2*Z-Y
      M=N-1
      DJD(1)=266.58
      DO 10 I=1,M
   10 DJD(I+1)=DJD(I)+DAYS(I)
      DJDR(1)=268.625
      DO 11 I=1,M
   11 DJDR(I+1)=DJDR(I)+DURA(I)
      DO 50 I=1,N
      XLOST(I)=(VIN(I)*78.084/(VOUT(I)*XN2(I))-1)*100.
      ALOST(I)=XLOST(I)*4.762*XN2(I)/3.719/100.
      CG1(I)=XCO(I)+XCO2(I)+XCH4(I)
      CG2(I)=4*XCH4(I)+2*XH2S(I)+2*XH2(I)
      CG3(I)=XCO(I)+2*XCO2(I)+2*XO2(I)-(2*XN2(I)/3.719)
      AA(I)=(2*CG3(I)-CG2(I))/B
      GG
      ACG(I)=CG3(I)-AA(I)*Z
      AL(I)=AA(I)*X-CG1(I)
      RCOC(I)=1.9353*((XCO(I)+XCO2(I)+XCH4(I))/XN2(I))
      RCOS(I)=RCOC(I)*(XN2(I)/(XN2(I)+XLOST(I)))
      GAMA(I)=2.082*(1/RCOC(I))*(ACG(I)/XN2(I))
      RAT(I)=XCO(I)/XCO2(I)
      RCH(I)=(XCO(I)+XCO2(I)+XCH4(I))*12.0/(4*XCH4(I)
     1+2*XH2S(I)+2*XH2(I)-2*ACG(I))
   50 PCRM(I)=(1.0-AL(I)/(AA(I)*.04037))*100
      K=4
      WRITE(6,100) K
```

```
100  FORMAT("1",4X,7H PHASE ,I1,
    138H FORWARD GASIFICATION AT PRICETOWN I,//)
     WRITE(6,101)
     DO 21 I=1,N
 21  WRITE(6,102) I,DJD(I),DAYS(I),DJDR(I),DURA(I),TIME(I),
    1KDIR(I),VIN(I),VOUT(I),P1(I),P2(I),P3(I)
101  FORMAT(3X,"STAGE",3X,"INITIAL",3X,"INITIAL",3X,
    1"ROUNDED",3X,"ROUNDED",3X,"TIME",3X," FLOW ",5X,
    1"SCFM",7X,"SCFM",6X,"P/I-1",5X,"P/I-2",5X,"P/I-3",/,
    113X,"JD",6X,"DURATION",5X,"JD",5X,"DURATION",2X,"(HRS)",2X," DIR",
    18X,"IN",8X,"OUT",22X,"(PSIA)",//)
102  FORMAT(4X,I2,5X,F7.3,1X,F7.3,5X,F7.3,2X,F7.3,4X,F5.2,4X,
    1I3,4X,2(F8.3,3X),3(F7.3,3X),/)
     WRITE(6,103)
     DO 22 I=1,N
 22  WRITE(6,104) I,DJDR(I),DURA(I),XH2(I),XN2(I),XCH4(I),
    1XCO(I),XO2(I),XH2S(I),XAR(I),XCO2(I)
103  FORMAT("1",2X,"STAGE",3X,"ROUNDED",3X,"ROUNDED",3X,"  H2 ",
    13X,"  N2 ",3X," CH4 ",3X,"  CO ",3X,"  O2 ",3X," H2S ",
    13X,"  AR ",3X," CO2 ",/,
    113X,"JD",6X,"DURATION",//)
104  FORMAT(4X,I2,5X,2(F7.3,3X),8(F5.2,3X),/)
     WRITE(6,105)
     DO 23 I=1,N
     AA(I)=AA(I)*X
     AL(I)=AL(I)*X
 23  WRITE(6,106) I,DJDR(I),DURA(I),AA(I),ACG(I),AL(I),XLOST(I),
    1PCRM(I),RCOC(I),RAT(I),RCH(I)
105  FORMAT("1",2X,"STAGE",3X,"ROUNDED",3X,"ROUNDED",3X," COAL  ",3X,
    1"NET H2O",3X,"  CHAR ",3X,"PER CENT",2X,"PER CENT",2X," R(C/O)"
    1,3X," CO/CO2",3X," R(C/H)",/,
    113X,"JD",6X,"DURATION",2X,"REACT",6X,"REACT",6X,"LEFT",4X,
    1 "AIR LOST",4X,"CHAR",/,71X,"REMOVED",//)
106  FORMAT(4X,I2,5X,5(F7.3,3X),F8.3,2X,4(F7.3,3X),/)
     STOP
     END
```

5.6 Nomenclature for FG (and CLE) Computer Programs

The following nomenclature is basically for the FG model main computer program but is essentially the same for the CLE model and UCG3D3 programs as well. Unless otherwise specified units used are ft, BTU, min, R, lbm, and radians. The Julian date is taken from January 1, 1979.

FORTRAN	Text	Description (units)
A	-	not used
ACONE	-	area of sector cone for velocity calculation
ACR	-	solid or char cross sectional area in link zone
AIRMW	M_a	air molecular weight
ALPHA	α	angle to middle of hemisphere sector (radians)
ALPHAT	α_T	angle for interpolating for link dia. or width
ALPHAN	α_N	angle to end of hemisphere sector
ALT	-	altitude of triangle in hemisphere sector
ARLZ	-	void cross sectional area in link zone
AS	A_{cs}	corss sectional area of cavity
AW	A_w	total cavity wall area of section k
A1-A4	-	intermediate energy variables
BMW	M_b	blast molecular weight
B1-B3	-	effective total heat capacities
CAFF	$m_{,coal,aff}$	mass of coal affected (tons)
CC	m_{coal}	coal consumed (tons)
CDIA	-	variable when using POLFIT for smoothing
CHC	m_{ch}	char consumed (tons)

FORTRAN	Text	Description (units)
CHLNTH	L_c	characteristic circulation length
CIRC	N	No. of circulations through $k^{\underline{th}}$ section in cylinder region
CIRCT1	N_o	circulation constant in exponential mixing
COCO2	-	molar ratio of CO to CO_2
CPAIR	$C_{p,a}$	specific heat capacity of air (BTU/lbm-R)
CPASH	$C_{p,ash}$	specific heat capacity of solid ash
CPCO	$C_{p,CO}$	specific heat capacity of CO
CPCOAL	$C_{p,coal}$	specific heat capacity of solid coal
CPCO2	$C_{p,CO2}$	specific heat capacity of CO_2
CPGAS	$C_{p,b}$	specific heat capacity bulk gas (~air)
CPH2	$C_{p,H2}$	specific heat capacity H_2
CPH2O	$C_{p,H2O}$	specific heat capacity steam
CPN2	$C_{p,N2}$	specific heat capacity N_2
CPO2	$C_{p,O2}$	specific heat capacity O_2
CPS	$C_{p,S}$	specific heat capacity solid sulfur
CPSO2	$C_{p,SO2}$	specific heat capacity SO_2
C11-C22	-	intermediate determinant variables
DALPHA	$\Delta\alpha$	sector angle size (radians)
DAY	t	time from start (days)
DAYJ0	-	initial Julian date (JD)
DAYJ1	-	Julian date at start of stage (JD)
DAYJ2	-	Julian date at end of stage (JD)
DAYMAX	-	time at end of burn (days)
DCIRC	ΔN	change in CIRC across a section

FORTRAN	Text	Description (units)
DDIA	-	variable when using POLFIT for smoothing
DDLZ	-	change in DLZ during one time interval
DELSL	Δs	are length in sector
DELT	-	temperature iteration size
DELTAT	Δt	finite difference time interval (hours)
DFRST	-	term in evaluation of determinant of T_w
DIA	d	diameter or width of cavity
DIAL	-	stored DIAX just prior to FG
DIAX	-	diameter or width of link zone during burn
DIN	-	scale diameter or width for plotting
DIP	-	negative DIN
DLZ	-	diameter or width of char zone during FG
DNC	d_{nc}	characteristic length in natural convection
DO	D_o	diffusion coefficient of oxygen in air (sq ft/min)
DRHC	Δr	change in radius due to coal consumption
DSCND	-	term in determinant evaluation for T_w
DURA	-	time duration of stage
DZCH	d_z	thickness of devolatilized region when cavity is near virgin coal
F	-	not used
FCHR	$F_{ch,R}$	fraction of char reacting
FK	k	k in floating point
FKNH	k_h	k_h in floating point
FLRMA	$\dot{m}_a$	mass flow rate of injected air
FLRMAC	-	mass flow rate of air entering cylinder region

FORTRAN	Text	Description (units)
FLRMAL	$\dot{m}_{a,L}$	mass flow rate of air mixed in internal direction
FLRMAM	$\dot{m}_{a,M}$	mass flow rate of air (newly) mixed
FLRMAR	$\dot{m}_{a,R}$	mass flow rate of air mixed in radial direction
FLRMAS	$\dot{m}_{a,S}$	mass flow rate of air not mixed
FLRMBL	$\dot{m}_{b,L}$	mass flow rate of mixed bulk gas
FLRMBS	$\dot{m}_{b,S}$	mass flow rate of bulk and mixed air leaving section
FLRMBT	$\dot{m}_{b,T}$	total mass flow rate of section
FLRMBV	$\dot{m}_{b,V}$	total mass flow rate for velocity calculation
FLRMBX	$\dot{m}_{b,x}$	total mass flow rate
FLRMCR	$\dot{m}_{c,R}$	total mass flow rate of carbon in radial direction
FLRMOL	$\dot{m}_{ox,L}$	total mass flow rate of oxygen lateral to wall
FLRMOS	$\dot{m}_{ox,S}$	total mass flow rate of (mixed) oxygen leaving section
FLRMOY	$\dot{m}_{ox,w}$	total mass flow rate of oxygen reaching wall
FN	-	fraction of air exponentially mixed
FNK	-	fraction of hemisphere to end of $k^{\underline{th}}$ sector
FOFTI	-	intermediate variable in temperature iteration
FOX	F_{ox}	fraction of coal consumed by oxidation reaction
FOXCH	$F_{ox,ch}$	fraction of char consumed by oxidation reaction
FWG	F_{wg}	fraction of coal consumed by reduction reaction
FWGCH	$F_{wg,ch}$	fraction of char consumed by reduction reaction

FORTRAN	Text	Description (units)
GC	g	gravitational constant or acceleration of gravity
GCHR	$\gamma_{ch,R}$	mass ratio of water reacting per char consumed
GMMN	$\gamma_{R,min}$	minimum γ_R
GMR	γ_R	mass ratio of water reacting to coal consumed
GMRCH	$\gamma_{R,ch}$	GCHR times YEC (lbm w/lbm coal)
GMRMX	$\gamma_{R,m}$	maximum γ_R depending on ultimate analysis
GMT	γ_T	mass ratio of total water available to coal consumed
GMXS	γ_{xs}	equals $\gamma_T - \gamma_R$
GOXW	$G_{ox,w}$	mass velocity of oxygen to wall
HC	h_c	heat transfer coefficient
HCCO	$\Delta h_{c,CO}$	enthalpy of formation of CO
HCCO2	$\Delta h_{c,CO2}$	enthalpy of formation of CO_2
HCH2O	$\Delta h_{c,H2O}$	enthalpy of formation of steam
HCSO2	$\Delta h_{c,SO2}$	enthalpy of formation of SO_2
HEIGHT	-	characteristic height in natural convection
HFGH2O	h_{fg}	enthalpy of vaporization of water
HM	h_m	mass transfer coefficient (sq. ft/min)
HMF	$h_{m,fc}$	mass transfer in forced convection
HMN	$h_{m,nc}$	mass transfer in natural convection
HR	$h_{rad,w}$	effective radiative heat transfer coefficient, not used
HRB	$h_{rad,B}$	HR for the burden wall
HRWG	$\Delta h_{R,wg}$	enthalpy of reaction, water-gas reaction
HSLASH	$h_{s\ell,ash}$	enthalpy of fusion of ash

FORTRAN	Text	Description (units)
HSLS	$h_{s\ell,S}$	enthalpy of fusion of sulfur
I	i	time index
IBUF	-	array for plotting
ITER	-	iteration counter
JJ7	-	miscellaneous index
K	k	sector index
KCHR	-	equals 1 if char reaction (Method II), otherwise 2
KD	$k_{max}+1$	No. of sectors incl. next sector from li[illegible]
KDIR	-	flow direction index
KK	-	index for link input dimensions and QLINKE
KMAX	k_{max}	No. of sections in cavity
KNH	k_h	No. of sections in hemisphere
KSEAM	-	equals 1 if circular, 2 if rectangular cross section
KSMLZ	-	KSEAM equivalent in QLINKE subroutine
L	-	miscellaneous index
N	-	maximum number of time iterations
NDAY	-	intergerized day for print/plot
NDPTS	-	number of data points to be used in POLFIT or INTERP
NI-NIII	-	indicies in temperature iteration scheme
NPTS	-	number of data points for POLFIT, INTERP OR SMOOTH
NTERMS	-	number of terms to be used in POLFIT or INTERP
NTHICK	-	equals 1 if optically thick, otherwise 2
N4	-	limit index in temperature iteration scheme

FORTRAN	Text	Description (units)
P	p	pressure (input as psia)
PI	π	pi
POR	P	porosity of coal
PR	Pr	Prandtl No.
QCONV	$Q_{c,w}$	convection heat transfer, wall to bulk gas
QCONVB	$Q_{c,B}$	convection heat transfer, bulk gas to burden wall
QFG	q_{fg}	effective latent heat sink terms
QOX	q_{ox}	effective oxidation energy source
QRAD	$Q_{rad,w}$	radiation heat transfer from $k^{\underline{th}}$ reacting wall
QRADB	$Q_{rad,BW}$	radiation heat transfer to $k^{\underline{th}}$ burden wall
QRADBTK	-	QRADB with optically thick gas
QRADTK	-	QRAD with optically thick gas
QWG	q_{wg}	effective reduction energy sink
RA	Ra	Rayleigh number
RCHNR	$R_{ch,NR}$	mass fraction of char not reacting during FG
RCHO2	$R_{ch/O}$	mass ratio of char reacting to oxygen supplied
RCONE	-	radius of base of sector cove
RCO1	$R_{c/o,1}$	mass ratio of coal consumed to oxygen supplied, Method I
RCO2	$R_{c/o,2}$	mass ratio of coal consumed to oxygen supplied, Method II
RE	Re	Reynolds number
RHC	r_{hc}	sector radius from origin (inj. well)
RHCLE	-	sector radius in link zone
RHC1	$r_{hc,1}$	radius of initial cavity volume formed

FORTRAN	Text	Description (units)
RHOAS	$\rho_{a,s}$	density of standard air (lbm/cu. ft)
RHOS	ρ_b	bulk gas density (lbm/cu. ft)
RHOC	ρ_{coal}	density of coal (lbm/cu. ft)
RNU	-	ratio of curvilinear to flat plate Nusselt No.
RVMO2	$R_{vm/O}$	ratio of volatile matter consumed to oxygen supplied
SCFM	$\dot{V}_{inj}$	volume flow rate of injected air
SCH	Sc	Schmdt No.
SFN	-	sum of FN's to k in cylinder sections
SIGM	σ	Stefan-Boltzmann constant
SL	s	distance along wall from x_{min}
SMTK	y_s	coal seam thickness (ft)
SMTK1	-	input variation on seam thickness
SSS	-	miscellaneous index
TAIR	T_a	injection air temperature (R)
TBK	-	mean (hem.) or leaving (cyl.) bulk temperature
TBKMN	$T_{b,m}$	calculated mean section bulk temperature
TBKMN1	-	iterated mean section bulk temperature
TB1	T_b	stored bulk temperature leaving section
TCIRC	-	temperature used in VBLAV calculation
TERM	-	exponential in restricted flow expression
TFILM	T_f	boundary layer film reference temperature
TI	-	iteration temperature
TI1-TI2	-	used in temperature iteration scheme
TL	x	axial distance (ft) from injection well

FORTRAN	Text	Description (units)
TLAV	-	distance to end of cavity to interpolate for link diameter
TLMAX	-	effective maximum x (set equal to maximum well distance)
TLP	-	scale axial distance for plots
TLX	-	input x value of link from CLE model
TLZ1	-	temperature leaving cavity into link zone
TO1-TO2	-	used in temperature convergence scheme
TREF	T_{ref}	variable reference temperature
TREFCH	$T_{ref,ch}$	reference temperature based on char temperature
TREFCL	$T_{ref,c}$	reference temperature based on virgin coal temperature
TVOL	T_{de}	assumed devolatilization temperature
TWALL	-	initial wall temperature value (R)
TWB	$T_{w,b}$	burden wall temperature
TW1	T_{w}	iterated wall temperature
VBLAV	$u_{b\ell}$	natural convection boundary layer velocity (ft/min)
VELB	u	axial bulk velocity (ft/min)
VHC1	$V_{hc,1}$	cavity volume after initial time interval burn
VMC	m_{vm}	volatile matter consumed (tons)
WFRCT	$F_{w,R}$	fraction of coal wall area entering reaction
WOX	W_{ox}	oxygen mass fraction in mixed bulk gas
WOXT	$W_{ox,T}$	oxygen mass fraction in total bulk flow
WO2	W_{O2}	oxygen mass fraction in injected air
WTEXMX	-	weighting factor - not used

FORTRAN	Text	Description (units)
WTHMS	-	weighting factor - not used
XI	-	x variable when use POLFIT smoothing
XL	s	distance along wall from bow at x_{min}
XMIN	X_{min}	maximum upstream cavity X value
YASH	Y_{ash}	ultimate and proximate analysis, ash + nitrogen
YC	Y_C	ultimate analysis, carbon
YFC	Y_{FC}	proximate analysis, fixed carbon
YH	Y_H	ultimate analysis, hydrogen
YMOIST	Y_M	ultimate and proximate analysis, moisture
YOX	Y_{ox}	ultimate analysis, oxygen
YS	Y_S	ultimate analysis, sulfur
YVM	Y_{vm}	proximate analysis, volatile matter
ZB	$\partial A_x/\partial X$	change in coal wall area wrt axial distance

5.7 CLE Model Computer Program: CLES60

```
      PROGRAM CLES60(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE2)
C     THE SUBMIT VERSION OF CLEN49 WITH DCR RE POR**.667 & RCL SCFM INPUT
C     THIS IS THE FINAL CLE PROGRAM AS OF DEC. 31, 1982.
C ***** THIS PROGRAM IS SAVED UNDER...LINKP20GM...*****
C          PROGRAM INCLUDES BOTH NAT. + FORCED CONV.
C     PROGRAM: UCG MODEL IIIA WITH SIMPLE ENERGY BALANCE
C     ALL CALCULATIONS ARE IN UNITS OF FT,LBM,MIN,BTU,R.
C     INPUT AND OUTPUT VALUES ARE CONVERTED BEFORE CALCULATIONS
C     OR PRINT-OUT,RESPECTIVELY.
C     PRESSURES ARE IN PSIA, ALL VELOCITIES ARE IN FT/MIN
      DIMENSION RNU(137),TLT(15),DIAT(15),ALPHN(137),CIRC(137)
      DIMENSION IBUF(512),XA(40),CDIA(40),DDIA(40),A(6)
     1  ,ALPHAT(8),RNUT(8)
      COMMON N,KMAX5,TL(137),DIA(137),DIP(137),DIN(137),TLP(137),DAY,
     *KDIR,ALPHA(137),DALPHA(137),XL(137),RHC(137),KSEAM(137)
C
      CALL PLOTS(IBUF,512,2,50)
C ***** LIST OF PROGRAM VARIABLES *****
C
      N=497
      D1=2.10
      D2=2.17
      DPOR1=0.0123
      DPOR2=0.05
      SMTK=7.00
      TOTL2=45.0
      DELTAT=3.0
      KROW=1
      CIRCT1=6.0
      DAYJO=160.500
      DAYLE1=6.00
      DAYLE2=30.125
      DAYLE3=44.000
      DAYLE4=70.750
      DAYMAX=106.125
      KRCL=0
C
C * ENTER VOLATILE MATTER CONSUMED DURING LINKING IF WANT RCL+CLE. *
C
      VMC=0.0
      VMC1=2.46
      VMC2=3.40
      SCFM=35.38
      SCFM2=12.31
      TBC=760.0
```

```
      TBH=1510.0
      TW=1710.0
      TINF=510.0
      DELXL=1.0
C
C ***** LIST OF COAL PROPERTIES *****
      GMXS=0.0
C
      GMRMX=0.695
      YC=0.7206
      YH=0.0482
      YS=0.04292
      YOX=0.05235
      YMOIST=0.01382
      YASH=0.1215
      YVM=0.3808
      YFC=1.0-YVM-YMOIST-YASH
      RHOC=79.29
      PDR=YVM
      DD=0.00003
C
C ***** LIST OF PROGRAM CONSTANTS *****
C
      KPLOT=1
      PI=3.1416
      BMW=29.0
      AIRMW=29.0
      CPB=0.276
      SCH=0.95
      RHOAS=.075
      WO2=0.23
      PR=0.8
      DO=.0139
      GC=32.2*3600.

***** INITIAL CALCULATIONS *****

      GMT=YMOIST+GMXS

320   KNH=8
      KMAX1=68
      KMAX2=76
      KMAX3=53
      KMAX4=61
      KMAX5=137
      KMAX6=84
      KMAX7=129

* WELL POSITION(X-AXIS) *

      XPOS1=0.0
```

```
      XPOS2=60.0
      XPOS3=105.0
      DO 18 KKK=1,KMAX5
      TL(KKK)=0.0
      DIA(KKK)=0.0
      KSEAM(KKK)=1
      CIRC(KKK)=1.00E-10
      DALPHA(KKK)=0.0
      RHC(KKK)=0.0
   18 CONTINUE
      DO 23 L=1,KNH
      LL=KMAX2-L+1
      LLL=KMAX5-L+1
      LLLL=KMAX2+L
      READ(5,24)ALPHA(L),RNU(L),ALPHN(L),DALPHA(L)
   24 FORMAT(F6.4,3X,F5.3,3X,F6.4,3X,F6.4)
      ALPHA(LL)=ALPHA(L)
      ALPHA(LLL)=ALPHA(L)
      ALPHA(LLLL)=ALPHA(L)
      RNU(LL)=RNU(L)
      RNU(LLL)=RNU(L)
      RNU(LLLL)=RNU(L)
      ALPHN(LL)=ALPHN(L)
      ALPHN(LLL)=ALPHN(L)
      ALPHN(LLLL)=ALPHN(L)
      DALPHA(LL)=DALPHA(L)
      DALPHA(LLL)=DALPHA(L)
      DALPHA(LLLL)=DALPHA(L)
      WRITE(6,602)ALPHA(L),RNU(L),ALPHN(L),DALPHA(L)
C 602 FORMAT(2X,'ALPHA(K)    RNU(K)   ALPHN(K)   DALPHA(K)'/2X,F6.4,6X,F
C    *5.3,6X,F6.4,6X,F6.4)
   23 CONTINUE
      DO 20 K=KNH+1,KMAX1
      RNU(K)=1.0
   20 CONTINUE
      DO 16 K=KMAX6+1,KMAX7
      RNU(K)=1.0
   16 CONTINUE
C
C ***** SET INITIAL CONDITIONS *****
C
      DAY=DAYLE1
    8 KRCL=KRCL+1
      IF(KRCL.EQ.1)VMC=VMC1
      IF(KRCL.EQ.2)VMC=VMC+VMC2
      JCOUNT=0
      IF(KRCL.EQ.2)DAY=DAYLE3
      IF(KRCL.EQ.2)SCFM=SCFM2
      DAY2=DAY-1.0
C
C ***** INITIAL CLE AFFECTED REGION AFTER RCL BURN(S) *****
C
```

```
      WRITE(6,50)
   50 FORMAT(//,3X,'I    K    DAY    TL(K)    D(K) VMC(TONS)     WOX',/)
      I=0
      RHC1=D1/2.0
      IF(KRCL.EQ.2)RHC1=D2/2.0
      WOX=WO2
C
C * * * CALCULATION OF INITIAL CLE SHAPE DIMENSIONS * * *
C
      XMIN2=XPOS2-RHC1
      IF(KRCL.EQ.2)XMIN1=-RHC1
      KNN8=KMAX2+1
      IF(KRCL.EQ.2)KNN8=1
      KNN9=KMAX6
      IF(KRCL.EQ.2)KNN9=KNH
      DO 40 K=KNN8,KNN9
      KK=K
      RHC(KK)=RHC1
C
C***** TL IS DIST. TO CENTER OF SUB-SECTOR AREA *****
C***** XL IS THE PROJECTION OF SUB-SECTOR WALL AREA ON AXIS *****
C
      TL(KK)=XPOS2-RHC(KK)*COS(ALPHA(KK))
      IF(KRCL.EQ.2)TL(KK)=-RHC(KK)*COS(ALPHA(KK))
      XL(KK)=2.0*RHC(KK)*SIN(DALPHA(KK)/2.0)*SIN(ALPHA(KK))
      DIA(KK)=2.0*RHC(KK)*SIN(ALPHA(KK))
   40 CONTINUE
      KK=KMAX6
      IF(KRCL.EQ.2)KK=KNH
      TL(KK)=XPOS2
      IF(KRCL.EQ.2)TL(KK)=XPOS1
      KNN=KMAX6+1
      IF(KRCL.EQ.2)KNN=KNH+1
      KNN1=KMAX7
      IF(KRCL.EQ.2)KNN1=NRCL-1
      DO 42 K=KNN,KNN1
      KK=K
      XL(KK)=1.00
      TL(KK)=TL(KK-1)+XL(KK)
      DIA(KK)=D1
      IF(KRCL.EQ.2)DIA(KK)=D2
   42 CONTINUE
      IF(KRCL.EQ.2)XMAX2=XMAX3
      TL(KMAX7)=XPOS3
      TL(KMAX1)=XPOS2
      IF(KRCL.EQ.2)GOTO44
      KNN2=KMAX7+1
      DO 43 K=KNN2,KMAX5
      KK=K
      RHC(KK)=RHC1
      TL(KK)=XPOS3+RHC(KK)*COS(ALPHA(KK))
```

```
      XL(KK)=2.0*RHC(KK)*SIN(DALPHA(KK)/2.0)*SIN(ALPHA(KK))
      DIA(KK)=2.0*RHC(KK)*SIN(ALPHA(KK))
   43 CONTINUE
   44 K1=KMAX6-7
      IF(KRCL.EQ.2)K1=1
      K2=KMAX5
      IF(KRCL.EQ.2)K2=KMAX1
      DO 31 J=1,KRCL
      DO 30 L=K1,K2
      WRITE(6,98)I,L,DAY,TL(L),DIA(L),VMC,WO2
   98 FORMAT(I4,1X,I3,1X,F6.2,1X,F6.2,1X,F6.2,1X,F8.2,3X,F6.4)
   30 CONTINUE
      K1=KMAX6+1
   31 K2=KMAX5
C
C     PLOT TITLE, AXIS + RCL WITH 2-D PLOT
C
      IF(ABS(DAY-6.).LT.0.1)GO TO 9001
      IF(ABS(DAY-44.).LT.0.1)GO TO 9001
      GO TO 9000
 9001 CALL PLTBKG
C
      CALL PLT2D(SCFM,DAYLE2)
      CALL PLOT(10.,0.,-3)
 9000 CONTINUE
C ***** ENTER TIME INTERVALS AND FLOW SCHEDULE *****
C
 1001 DO 22 I=1,N
      JCOUNT=JCOUNT+1
      IF(JCOUNT.GT.16)JCOUNT=1
      DAY=DAY+DELTAT/24.0
      IF(DAY.LT.(DAY2+.01))GO TO 35
      IF((DAY.GE.(DAYLE2+.01)).AND.(DAY.LT.(DAYLE3-.01)))GO TO 215
      READ(5,3555)DAYJ1,DURA,RVMO2,SCFM,P,KDIR
 3555 FORMAT(3X,5(F10.3,3X),I10)
      DAY2=DAYJ1+DURA-DAYJO
C
C * RVM + RVO2 CALCULATIONS *
C
C * RVO2 INCLUDES THE MOISTURE + VOLATILE MATTER IN THE COAL *
C * RVM CALCULATION FOR MODELING W/O EXPERIMENTAL DATA *
C
      IF(RVMO2.GT.0.0)GOTO333
C     RVMO2=(1.0+(GOX+GCH)/(HDEVOL+GCH))/(1.333*(YC-YFC)+8.0*YH+YS/2.0
C    *-YOX)
  333 RVO2=RVMO2*(1.0+YMDIST/YVM)
      WRITE(6,3556)DAYJ1,DAY,SCFM,RVMO2,KDIR
 3556 FORMAT(5X,'DAYJ1=',F10.3,'  DAY=',F10.3,'  SCFM=',F10.3,
     1   '  RVMO2=',F10.3,'  KDIR=',I4)
   35 FLRMA=RHOAS*SCFM
      IF((KDIR.EQ.32).OR.(KDIR.EQ.321).OR.(KDIR.EQ.31)
     1  .OR.(KDIR.EQ.23))KROW=1
```

```
      IF((KDIR.EQ.12).OR.(KDIR.EQ.123).OR.(KDIR.EQ.13)
     1  .OR.(KDIR.EQ.21))KROW=2
      IF(DAY.GE.DAYMAX-.01)GOTO 45
  334 IF(JCOUNT.NE.16)GOTO46
      IF(ABS(DAY-16.0).LT.0.1)GO TO 45
      IF(ABS(DAY-30.125).LT.0.1)GO TO 45
      IF(ABS(DAY-70.750).LT.0.1)GO TO 45
      IF(ABS(DAY-90.).LT.0.1)GO TO 45
      IF(ABS(DAY-10.).LT.0.1)GO TO 45
      IF(ABS(DAY-44.).LT.0.1)GO TO 45
      IF(ABS(DAY-100.).LT.0.1)GO TO 45
      IF(ABS(DAY-50.0).LT.0.1) GO TO 45
      IF(ABS(DAY-48.875).LT.0.1)GO TO 45
      GO TO 46
   45 WRITE(6,3555)DAYJ1,DURA,RVMO2,SCFM,P,KDIR
      WRITE(6,51)
   51 FORMAT(//,3X,'I   K   DAY    TL(K)  D(K)  FLMBL FLMOY FLMOL HNAT
     * FLRMBV FLRMVR  VELB  VMC(TONS)   WOX   GOXW    DCIRC    HTOTL   S
     *   FN ',/)
      WRITE(6,10)SCFM,RVO2,P,DELTAT,RHOC,POR,N
   10 FORMAT(//,T10,'SCFM  =',F10.2,T30,'RVO2  =',F10.2,T50,'P     =',F1
     *0.2,/,T10,'DELTAT=',F10.2,T30,'RHOC   =',F10.2,T50,'PORSTY=',F10.4
     *,/,T10,'N INT =',I8,//)

***** HEMISPHERICAL + STEP-CYLINDER REGIONS *****

   46 KNN4=KMAX2+1
      DPOR=DPOR1
      IF(DAY.GT.DAYLE4+.01)DPOR=DPOR2
      IF(KROW.EQ.2)KNN4=1
      IF((KDIR.EQ.321.OR.KDIR.EQ.31).AND.(KROW.EQ.2))KNN4=KNH+1
      IF((KDIR.EQ.123.OR.KDIR.EQ.13).AND.(KROW.EQ.1))KNN4=KMAX6+1
      KNN5=KMAX7
      IF(KROW.EQ.2)KNN5=KMAX1
   48 DO 7 K=KNN4,KNN5
      IF(KROW.EQ.2)GOTO395
      KK=K
      IF(KDIR.EQ.32.OR.KDIR.EQ.31.OR.KDIR.EQ.321)KK=KMAX5+KNN4-K
      GOTO401
  395 KK=K
      IF(KDIR.EQ.21)KK=KMAX2-K+1
      IF(KDIR.EQ.31.OR.KDIR.EQ.321)KK=KMAX1+KNH+1-K
  401 CONTINUE
      IF(KSEAM(KK).EQ.2)GOTO411
      IF(DIA(KK)-1.128*SMTK)405,402,402

* * * THIN SEAM (KSEAM=2) RELATIONS * * *

  402 KSEAM(KK)=2
      DIA(KK)=(PI*DIA(KK)**2/4.0)/SMTK
      IF(KROW.EQ.2)GOTO797
```

```
      IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO796
      IF(KK.GT.KMAX7)RHC(KK)=DIA(KK)/(2.0*SIN(ALPHA(KK)))
      GOTO799
  796 IF(KK.LE.KMAX6)RHC(KK)=DIA(KK)/(2.0*SIN(ALPHA(KK)))
      GOTO799
  797 IF((KDIR.EQ.12).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO798
      IF(KK.GT.KMAX1)RHC(KK)=DIA(KK)/(2.0*SIN(ALPHA(KK)))
      GOTO799
  798 IF(KK.LE.KNH)RHC(KK)=DIA(KK)/(2.0*SIN(ALPHA(KK)))
  799 RC=DIA(KK)/2.0
  411 AS=SMTK*DIA(KK)
C     DNC=SMTK
      DNC=DPOR
      CHLNTH=2.0*SMTK+DIA(KK)
      IF(KROW.EQ.2)GOTO801
      IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO800
      IF(KK.GT.KMAX7)AS=SMTK*RHC(KK)*2.0
      IF(KK.GT.KMAX7)AW=2.0*(SMTK*RHC(KK)*DALPHA(KK)+DIA(KK)*XL(KK))
      IF(KK.GT.KMAX7)WFRCT=2.0*SMTK*RHC(KK)*DALPHA(KK)/AW
      AW=2.0*SMTK*XL(KK)+2.0*DIA(KK)*XL(KK)
      WFRCT=2.0*SMTK*XL(KK)/AW
      GOTO803
  800 IF(KK.LE.KMAX6)AS=SMTK*RHC(KK)*2.0
      IF(KK.LE.KMAX6)AW=2.0*(SMTK*RHC(KK)*DALPHA(KK)+DIA(KK)*XL(KK))
      IF(KK.LE.KMAX6)WFRCT=2.0*SMTK*RHC(KK)*DALPHA(KK)/AW
      AW=2.0*SMTK*XL(KK)+2.0*DIA(KK)*XL(KK)
      WFRCT=2.0*SMTK*XL(KK)/AW
      GOTO803
  801 IF((KDIR.EQ.12).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO802
      IF(KK.GT.KMAX1)AS=SMTK*RHC(KK)*2.0
      IF(KK.GT.KMAX1)AW=2.0*(SMTK*RHC(KK)*DALPHA(KK)+DIA(KK)*XL(KK))
      IF(KK.GT.KMAX1)WFRCT=2.0*SMTK*RHC(KK)*DALPHA(KK)/AW
      AW=2.0*SMTK*XL(KK)+2.0*DIA(KK)*XL(KK)
      WFRCT=2.0*SMTK*XL(KK)/AW
      GOTO803
  802 IF(KK.LE.KNH)AS=SMTK*RHC(KK)*2.0
      IF(KK.LE.KNH)AW=2.0*(SMTK*RHC(KK)*DALPHA(KK)+DIA(KK)*XL(KK))
      IF(KK.LE.KNH)WFRCT=2.0*SMTK*RHC(KK)*DALPHA(KK)/AW
      AW=2.0*SMTK*XL(KK)+2.0*DIA(KK)*XL(KK)
      WFRCT=2.0*SMTK*XL(KK)/AW
C 803 DNC=SMTK
  803 DNC=DPOR
      CHLNTH=2.0*SMTK+2.0*RHC(KK)
      GOTO423
C
C * * * THICK SEAM (KSEAM=1) RELATIONS * * *
C
  405 WFRCT=1.0
      IF(KROW.EQ.2)GOTO805
      IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO804
      IF(KK.LE.KMAX7)GOTO404
```

```
      GOTO807
  804 IF(KK.GT.KMAX6)GOTO404
      GOTO807
  805 IF((KDIR.EQ.12).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO806
      IF(KK.LE.KMAX1)GOTO404
      GOTO807
  806 IF(KK.GT.KNH)GOTO404
C
C * * * FOR THICK SEAM IN HEMISPHERE(KSEAM=1 + K.LE.KNH) * * *
C
  807 AW=PI*DIA(KK)*RHC(KK)*DALPHA(KK)
      CHLNTH=PI*RHC(KK)+2.0*RHC(KK)
C     DNC=2.0*RHC(KK)
      DNC=DPOR
      GOTO423
C
C * * * FOR THICK SEAM IN STEP-CYL. REG.(KSEAM=1 + K.GT.KNH) * * *
C
  404 AW=PI*DIA(KK)*XL(KK)
      AS=PI*DIA(KK)**2/4.0
      RC=DIA(KK)/2.0
      CHLNTH=PI*DIA(KK)/2.0+DIA(KK)
C     DNC=DIA(KK)
      DNC=DPOR
  423 IF(KROW.EQ.2)GOTO809
      IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO808
      IF(KK.LT.KMAX5)GOTO902
      GOTO811
  808 IF(KK.GT.(KMAX2+1))GOTO902
      GOTO811
  809 IF((KDIR.EQ.12).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO810
      IF(KK.LT.KMAX2)GOTO902
      GOTO811
  810 IF(KK.GT.1)GOTO902

* * * FOR K=1 * * *

  811 FLRMAR=FLRMA/2.0*(1-COS(ALPHN(KK)))
      FLRMBL=0.0
      FLRMOL=0.0
      FLRMVR=0.0
      FLRMAL=0.0
      FLRMBV=FLRMAR
      DELSL=DALPHA(KK)*RHC(KK)
      SL=DELSL/2
      GOTO1819

* * * FOR K GREATER THAN 1 * * *

  902 IF(KROW.EQ.2)GOTO813
      IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO812
```

```
      IF(KK.LE.KMAX7)GOTO908
      GOTO815
  812 IF(KK.GT.KMAX6)GOTO908
      GOTO907
  813 IF((KDIR.EQ.12).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO814
      IF(KK.LE.KMAX1)GOTO908
      GOTO815
  814 IF(KK.GT.KNH)GOTO908
      GOTO907
  815 FLRMAR=FLRMA/2.0*(COS(ALPHN(KK+1))-COS(ALPHN(KK)))
      FLRMBV=FLRMBV+FLRMAR
      GOTO819
  907 FLRMAR=FLRMA/2.0*(COS(ALPHN(KK-1))-COS(ALPHN(KK)))
      FLRMBV=FLRMBV+FLRMAR
      GOTO819
  908 IF(KROW.EQ.2)GOTO817
      IF(KDIR.EQ.23)GOTO816
      IF((KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO819
      IF(KK.EQ.KMAX7)FLRMBV=FLRMBV+FLRMA/2.0
      GOTO819
  816 IF(KK.EQ.(KMAX6+1))FLRMBV=FLRMBV+FLRMA/2.0
      GOTO819
  817 IF((KDIR.EQ.12).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO818
      IF((KDIR.EQ.31).OR.(KDIR.EQ.321))GOTO819
      IF(KK.EQ.KMAX1)FLRMBV=FLRMBV+FLRMA/2.0
      GOTO819
  818 IF(KK.EQ.(KNH+1))FLRMBV=FLRMBV+FLRMA/2.0
  819 SL=SL+DELSL/2
      DELSL=DALPHA(KK)*RHC(KK)
      IF((KK.GT.KNH).AND.(KK.LE.KMAX1))DELSL=DELXL
      IF((KK.GT.KMAX6).AND.(KK.LE.KMAX7))DELSL=DELXL
      SL=SL+DELSL/2
 1819 RHO=P*144.0*BMW/(1545.0*TBH)
      IF(KSEAM(KK).EQ.2)GOTO403
      IF(KROW.EQ.2)GOTO821
      IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO820
      IF(KK.LE.KMAX7)GOTO403
      GOTO823
  820 IF(KK.GT.KMAX6)GOTO403
      GOTO823
  821 IF((KDIR.EQ.12).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO822
      IF(KK.LE.KMAX1)GOTO403
      GOTO823
  822 IF(KK.GT.KNH)GOTO403
C
C * * * FOR THICK SEAM AND K LESS THAN KNH (IN HEM.) * * *
C
  823 ALT=RHC(KK)*COS(ALPHA(KK))
      RCONE=DIA(KK)/2.0
      ACONE=PI*RCONE*SQRT(RCONE**2+ALT**2)
      VELB=FLRMBV/(RHO*ACONE)
      GOTO407
```

```
* * * FOR THIN SEAM AND STEP-CYLINDER REGION * * *

403 VELB=FLRMBV/(RHO*AS)
407 TFILM=(TW+TBH)/2
    VBLAV=0.173*(GC*ABS(TW-TBH)*DPOR/TFILM/(1.0+0.494*PR**
   1  0.667))**0.5
    DCIRC=DELSL*VBLAV/VELB/CHLNTH
    IF(DCIRC/CIRCT1.GT.300.0)DCIRC=300.0*CIRCT1
    IF(KROW.EQ.2)GOTO825
    IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO824
    IF(KK.LE.KMAX7)GOTO106
    GOTO827
824 IF(KK.GT.KMAXG)GOTO106
    GOTO827
825 IF((KDIR.EQ.12).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO826
    IF(KK.LE.KMAX1)GOTO106
    GOTO827
826 IF(KK.GT.KNH)GOTO106
827 FLRMAR=FLRMAL+FLRMAR
    FN=1.0-EXP(-DCIRC/CIRCT1)
    FLRMAS=FLRMAR*(1-FN)
    FLRMAM=FLRMAR*FN
    FLRMBS=FLRMBL+FLRMAM
    FLRMOS=FLRMOL+WO2*FLRMAM
    GOTO905
106 IF((KDIR.EQ.12.OR.KDIR.EQ.123.OR.KDIR.EQ.13)
   1  .AND.(KK.EQ.KNH+1))GOTO 400
    IF((KDIR.EQ.21).AND.(KK.EQ.KMAX1))GOTO 400
    IF((KDIR.EQ.23).AND.(KK.EQ.KMAXG+1))GOTO 400
    IF((KDIR.EQ.32.OR.KDIR.EQ.321.OR.KDIR.EQ.31)
   1  .AND.(KK.EQ.KMAX7))GOTO 400
    GOTO 406
400 FLRMAC=FLRMA/2.0+FLRMAL
    IF((KDIR.EQ.12).OR.(KDIR.EQ.123).OR.(KDIR.EQ.13)
   1  .OR.(KDIR.EQ.23))CIRC(KK-1)=0.0
    IF((KDIR.EQ.32).OR.(KDIR.EQ.321).OR.(KDIR.EQ.31)
   1  .OR.(KDIR.EQ.21))CIRC(KK+1)=0.0
    FN=0
    SFN=0
406 IF((KDIR.EQ.32).OR.(KDIR.EQ.321).OR.(KDIR.EQ.31)
   1  .OR.(KDIR.EQ.21))GOTO408
    IF((KDIR.EQ.13.OR.KDIR.EQ.123).AND.KK.EQ.KMAXG+1)CIRC(KMAXG)
   1  =CIRC(KMAX1)
    CIRC(KK)=CIRC(KK-1)+DCIRC
    FN=EXP(-CIRC(KK-1)/CIRCT1)-EXP(-CIRC(KK)/CIRCT1)
    GOTO 409
408 IF((KDIR.EQ.31.OR.KDIR.EQ.321).AND.KK.EQ.KMAX1)
   1  CIRC(KMAX1+1)=CIRC(KMAXG+1)
    CIRC(KK)=CIRC(KK+1)+DCIRC
    FN=EXP(-CIRC(KK+1)/CIRCT1)-EXP(-CIRC(KK)/CIRCT1)
```

```
  409 CONTINUE
C     WRITE(6,555)CIRC(KK-1),CIRC(KK),DCIRC,FN
  555 FORMAT(3X,'CIRC(KK-1)= ',1E10.3,' CIRC(KK)= ',1E10.3,
     1   ' DCIRC= ',1E10.3,' FN= ',1E10.3)
      SFN=SFN+FN
      FLRMAS=FLRMAC*(1-SFN)
      IF(FLRMAS.LT.0)FLRMAS=0
      FLRMAM=FLRMAC*FN
      FLRMOS=FLRMOL+WO2*FLRMAM
  831 FLRMBS=FLRMBL+FLRMAM
C
C ***** HEAT AND MASS TRANSFER *****
C
  905 CONTINUE
C     WRITE(6,7777)P,BMW,TW,TBH,DNC,PR
C7777 FORMAT(6E15.3)
      CALL HMTR(VELB,P,BMW,PR,DO,CPB,PDR,SL,DNC,TBH,TW,RNU(KK),RE,R
     *HMF,HMN,HM)
C
C * * * RESTRICTED FLOW CALCULATION * * *
C
      IF(KROW.EQ.2)GOTO836
      IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO835
      IF(KK.LE.KMAX7)GOTO911
      GOTO838
  835 IF(KK.GT.KMAX6)GOTO911
      GOTO838
  836 IF((KDIR.EQ.12).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO837
      IF(KK.LE.KMAX1)GOTO911
      GOTO838
  837 IF(KK.GT.KNH)GOTO911
  838 ZB=PI*DIA(KK)/SIN(ALPHA(KK))
      IF(KSEAM(KK).EQ.2)ZB=2.0*SMTK/SIN(ALPHA(KK))
      GOTO912
  911 ZB=PI*DIA(KK)
      IF(KSEAM(KK).EQ.2)ZB=(AW*WFRCT)/XL(KK)
  912 IF(FLRMOS.LE.0.1E-73)GOTO913
      TERM=HM*ZB*XL(KK)*RHO/FLRMBS
      IF(TERM.GE.300.0)GOTO713
      FLRMOL=FLRMOS*EXP(-TERM)
      GOTO914
  913 FLRMOL=0.0
      FLRMOY=0.0
      GOTO915
  713 FLRMOL=0.0
  914 FLRMOY=FLRMOS-FLRMOL
  915 FLRMVR=RVO2*FLRMOY
C
C * * * CALCULATE NEW CAVITY SHAPE * * *
C
      DRHC=(FLRMVR*DELTAT*60.0)/(RHOC*AW*WFRCT*(YVM+YMOIST))
```

```
      IF(KROW.EQ.2)GOTO840
      IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO839
      IF(KK.LE.KMAX7)GOTO501
      GOTO842
  839 IF(KK.GT.KMAX6)GOTO501
      GOTO842
  840 IF((KDIR.EQ.12).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO841
      IF(KK.LE.KMAX1)GOTO501
      GOTO842
  841 IF(KK.GT.KNH)GOTO501

* * * FOR K LESS THAN KNH * * *

  842 RHC(KK)=RHC(KK)+DRHC
      DIA(KK)=2.0*RHC(KK)*SIN(ALPHA(KK))
      IF(KROW.EQ.2)GOTO917
      IF(KDIR.EQ.32.OR.KDIR.EQ.321.OR.KDIR.EQ.31)GOTO916
      IF(KK.EQ.(KMAX2+1))XMIN2=XPOS2-RHC(KK)
      TL(KK)=XPOS2-RHC(KK)*COS(ALPHA(KK))
      XL(KK)=2.0*RHC(KK)*SIN(DALPHA(KK)/2.0)*SIN(ALPHA(KK))
      GOTO502
  916 IF(KK.EQ.KMAX5)XMAX3=XPOS3+RHC(KK)
      TL(KK)=XPOS3+RHC(KK)*COS(ALPHA(KK))
      XL(KK)=2.0*RHC(KK)*SIN(DALPHA(KK)/2.0)*SIN(ALPHA(KK))
      GOTO502
  917 IF(KDIR.EQ.21)GOTO918
      IF(KK.EQ.1)XMIN1=-RHC(KK)
      TL(KK)=-RHC(KK)*COS(ALPHA(KK))
      XL(KK)=2.0*RHC(KK)*SIN(DALPHA(KK)/2.0)*SIN(ALPHA(KK))
      GOTO502
  918 IF(KK.EQ.KMAX2)XMAX2=XPOS2+RHC(KK)
      TL(KK)=XPOS2+RHC(KK)*COS(ALPHA(KK))
      XL(KK)=2.0*RHC(KK)*SIN(DALPHA(KK)/2.0)*SIN(ALPHA(KK))
      GOTO502
  501 DIA(KK)=DIA(KK)+2.0*DRHC
  502 FLRMBL=FLRMBS+FLRMVR*(1.0+GMXS)
      FLRMAL=FLRMAS
      FLRMBV=FLRMBV+FLRMVR*(1+GMXS)
      WOX=FLRMOL/FLRMBL
      VMC=VMC+FLRMVR*DELTAT*60.0/2000.0
      GOXW=FLRMOY/AW
      IF(DAY.GE.DAYMAX-.01)GOTO 84

AIT
      IF(JCOUNT.NE.16)GOTO7
      IF(ABS(DAY-16.0).LT.0.1)GO TO 84
      IF(ABS(DAY-30.125).LT.0.1)GO TO 84
      IF(ABS(DAY-70.750).LT.0.1)GO TO 84
      IF(ABS(DAY-90.).LT.0.1) GO TO 84
      IF(ABS(DAY-10.).LT.0.1)GO TO 84
      IF(ABS(DAY-44.).LT.0.1)GO TO 84
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```
C      IF(ABS(DAY-100.).LT.0.1)GO TO 84
C      IF(ABS(DAY-50.0).LT.0.1)GO TO 84
C      IF(ABS(DAY-49.875).LT.0.1)GO TO 84
C      GO TO 7
   84 WRITE(6,90)I,KK,DAY,TL(KK),DIA(KK),FLRMBL,FLRMDY,FLRMOL,HMN,FLRMBV
     *,FLRMVR,VELB,VMC,WOX,GOXW,DCIRC  ,HM,KSEAM(KK),FN
   90 FORMAT(I4,1X,I3,1X,F6.2,1X,F6.2,1X,F6.2,1X,3F6.3,1X,F6.3,1X,F6.3,1
     *X,F6.3,F6.3,F9.2,3X,F6.4,1X,F6.4,E10.3,1X,F6.2,2X,I2,2X,F6.4)
    7 CONTINUE
C
C * * * IF FLOW CONTINUES OVER SECOND WELL PAIR, SET UP NEW LIMITS
C       AND CONTINUE BACK TO DO7 LOOP, OTHERWISE GOTO PROD WELL * * *
C
      IF((KDIR.EQ.123.OR.KDIR.EQ.13).AND.(KK.EQ.KMAX1))GOTO191
      IF((KDIR.EQ.31.OR.KDIR.EQ.321).AND.(KK.EQ.(KMAX6+1)))GOTO192
      GOTO 197
  191 KROW=1
      IF(KDIR.EQ.123)GOTO196
      GOTO46
  192 KROW=2
      IF(KDIR.EQ.321)GOTO196
      GOTO46
  196 FLRMAL=FLRMAL/2.0
      FLRMOL=FLRMOL/2.0
      FLRMBL=FLRMBL/2.0
      FLRMBV=FLRMBV/2.0
      GOTO46
C
C * * * HEMISPHERICAL REGION AT THE PRODUCTION WELL * * *
C
  197 FLRMP=FLRMBL
      FLRMPT=FLRMBL/2.0
      DO 11 J=1,KNH
      IF(KROW.EQ.2)GOTO198
      KK=KMAX7+J
      IF(KDIR.EQ.32)KK=KMAX6+1-J
      GOTO199
  198 KK=KNH+1-J
      IF(KDIR.EQ.12)KK=KMAX1+J
  199 IF(KSEAM(KK).EQ.2)GOTO201
      IF(DIA(KK)-1.128*SMTK)202,200,200
  200 KSEAM(KK)=2
      DIA(KK)=(PI*DIA(KK)**2/4.0)/SMTK
      RHC(KK)=DIA(KK)/(2.0*SIN(ALPHA(KK)))
  201 AS=SMTK*RHC(KK)*2.0
      AW=2.0*(SMTK*RHC(KK)*DALPHA(KK)+DIA(KK)*XL(KK))
      WFRCT=2.0*SMTK*RHC(KK)*DALPHA(KK)/AW
C     DNC=SMTK
      DNC=DPOR
      GOTO203
  202 WFRCT=1.0
      AW=PI*DIA(KK)*RHC(KK)*DALPHA(KK)
```

```
C      DNC=2.0*RHC(KK)
       DNC=DPOR
  203  IF(KROW.EQ.2)GOTO220
       IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO219
       IF(KK.GT.(KMAX2+1))GOTO204
       GOTO222
  219  IF(KK.LT.KMAX5)GOTO204
       GOTO222
  220  IF(KDIR.EQ.12)GOTO221
       IF(KK.GT.1)GOTO204
       GOTO222
  221  IF(KK.LT.KMAX2)GOTO204
  222  FLRMPR=FLRMPT*(1-COS(ALPHN(KK)))
       GOTO205
  204  IF(KDIR.EQ.12)GOTO233
       IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO233
       FLRMPR=FLRMPT*(COS(ALPHN(KK-1))-COS(ALPHN(KK)))
       GOTO205
  233  FLRMPR=FLRMPT*(COS(ALPHN(KK+1))-COS(ALPHN(KK)))
  205  IF(KROW.EQ.2)GOTO224
       IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO223
       IF(KK.EQ.KMAX8)FLRMBL=FLRMBL/2.0
       GOTO226
  223  IF(KK.EQ.(KMAX7+1))FLRMBL=FLRMBL/2.0
       GOTO226
  224  IF(KDIR.EQ.12)GOTO225
       IF(KK.EQ.KNH)FLRMBL=FLRMBL/2.0
       GOTO226
  225  IF(KK.EQ.(KMAX1+1))FLRMBL=FLRMBL/2.0
  226  FLRMBV=FLRMBL
       RHO=P*144.0*BMW/(1545.0*TBH)
       IF(KSEAM(KK).EQ.2)GOTO206
       ALT=RHC(KK)*COS(ALPHA(KK))
       RCONE=DIA(KK)/2.0
       ACONE=PI*RCONE*SQRT(RCONE**2+ALT**2)
       VELB=FLRMBV/(RHO*ACONE)
       GOTO207
  206  VELB=FLRMBV/(RHC*AS)
  207  FLRMOS=FLRMOL
       IF(KROW.EQ.2)GOTO228
       IF((KDIR.EQ.23).OR.(KDIR.EQ.13).OR.(KDIR.EQ.123))GOTO227
       IF(KK.EQ.KMAX6)FLRMOS=FLRMOL/2.0
       GOTO230
  227  IF(KK.EQ.(KMAX7+1))FLRMOS=FLRMOL/2.0
       GOTO230
  228  IF(KDIR.EQ.12)GOTO229
       IF(KK.EQ.KNH)FLRMOS=FLRMOL/2.0
       GOTO230
  229  IF(KK.EQ.(KMAX1+1))FLRMOS=FLRMOL/2.0
  230  SL=SL+DELSL/2
       DELSL=RHC(KK)*DALPHA(KK)
```

```
      SL=SL+DELSL/2
      CALL HMTR(VELB,P,BMW,PR,DO,CPB,POR,SL,DNC,TBH,TW,RNU(KK),RE,RA,
     *HMF,HMN,HM)
      ZB=PI*DIA(KK)/SIN(ALPHA(KK))
      IF(KSEAM(KK).EQ.2)ZB=2.0*SMTK/SIN(ALPHA(KK))
      IF(FLRMOS.LE.0.1E-73)GOTO208
      IF(DAY.LT.49.0.OR.DAY.GT.52.5)GOTO995
C     WRITE(6,994)HMF,HMN,HM,ZB,XL(KK),RHO,FLRMBL
  994 FORMAT(2X,'HMF  HMN  HM  ZB  XL(KK)  RHO  FLRMBL',/,7(2X,E10.3))
  995 TERM=HM*ZB*XL(KK)*RHO/FLRMBL
      IF(TERM.GE.300.0)GOTO308
      FLRMOL=FLRMOS*EXP(-TERM)
      GOTO209
  208 FLRMOL=0.0
      FLRMOY=0.0
      GOTO210
  308 FLRMOL=0.0
  209 FLRMOY=FLRMOS-FLRMOL
  210 FLRMVR=RVO2*FLRMOY
      DRHC=(FLRMVR*DELTAT*60.0)/(RHOC*AW*WFRCT*(YVM+YMOIST))
      RHC(KK)=RHC(KK)+DRHC
      DIA(KK)=2.0*RHC(KK)*SIN(ALPHA(KK))
      IF(KROW.EQ.2)GOTO231
      IF(KDIR.EQ.32)GOTO211
      IF(KK.EQ.KMAX5)XMAX3=XPOS3+RHC(KK)
      TL(KK)=XPOS3+RHC(KK)*COS(ALPHA(KK))
      XL(KK)=2.0*RHC(KK)*SIN(DALPHA(KK)/2.0)*SIN(ALPHA(KK))
      GOTO212
  211 IF(KK.EQ.(KMAX2+1))XMIN2=XPOS2-RHC(KK)
      TL(KK)=XPOS2-RHC(KK)*COS(ALPHA(KK))
      XL(KK)=2.0*RHC(KK)*SIN(DALPHA(KK)/2.0)*SIN(ALPHA(KK))
      GOTO212
  231 IF(KDIR.EQ.21.OR.KDIR.EQ.31.OR.KDIR.EQ.321)GOTO232
      IF(KK.EQ.KMAX2)XMAX2=XPOS2+RHC(KK)
      TL(KK)=XPOS2+RHC(KK)*COS(ALPHA(KK))
      XL(KK)=2.0*RHC(KK)*SIN(DALPHA(KK)/2.0)*SIN(ALPHA(KK))
      GOTO212
  232 IF(KK.EQ.1)XMIN1=-RHC(KK)
      TL(KK)=-RHC(KK)*COS(ALPHA(KK))
      XL(KK)=2.0*RHC(KK)*SIN(DALPHA(KK)/2.0)*SIN(ALPHA(KK))
  212 FLRMBS=FLRMBL
      FLRMBL=FLRMBL-FLRMPR+FLRMVR*(1.0+GMXS)
      FLRMPT=FLRMPT+FLRMVR*(1.0+GMXS)
      FLRMP=FLRMP+FLRMVR*(1.0+GMXS)
      WOX=FLRMOL/FLRMBL
      VMC=VMC+FLRMVR*DELTAT*60.0/2000.0
      GOXW=FLRMOY/AW
      IF(DAY.GE.DAYMAX-.01)GOTO 213
      IF(JCOUNT.NE.16)GOTO11
C     IF(ABS(DAY-16.0).LT.0.1)GO TO 213
C     IF(ABS(DAY-30.125).LT.0.1)GO TO 213
```

```
C      IF(ABS(DAY-70.750).LT.0.1)GO TO 213
C      IF(ABS(DAY-90.).LT.0.1)GO TO 213
C      IF(ABS(DAY-10.).LT.0.1)GO TO 213
C      IF(ABS(DAY-44.).LT.0.1)GO TO 213
C      IF(ABS(DAY-100.).LT.0.1)GO TO 213
C      IF(ABS(DAY-50.0).LT.0.1)GO TO 213
C      IF(ABS(DAY-49.875).LT.0.1)GO TO 213
C      GO TO 11
  213 WRITE(6,214)I,KK,DAY,TL(KK),DIA(KK),FLRMBS,FLRMOY,FLRMOL,HMN,FLRMB
     *V,FLRMVR,VELB,VMC,WOX,GOXW,RA,HM,KSEAM(KK),SCFM
  214 FORMAT(I4,1X,I3,1X,F6.2,1X,F6.2,1X,F6.2,1X,3F6.3,1X,F6.3,1X,F6.3,1
     *X,F6.3,F6.3,F9.2,3X,F6.4,1X,F6.4,E10.3,1X,F6.2,2X,I2,2X,F5.0)
   11 CONTINUE
C
C * * * USE POLFIT TO SMOOTH DIAMETER AROUND INJECTION WELL
      IF((KDIR.EQ.13).OR.(KDIR.EQ.123))KROW=2
      NPT1=24+DAY/10
      SS=0.
      DO 3501 JJ1=1,NPT1
      SS=SS+1.
 3501 XA(JJ1)=SS
      DO 3502 JJ2=1,NPT1
      IF((KDIR.EQ.321).OR.(KDIR.EQ.31).OR.(KDIR.EQ.32))LL=KMAX5-JJ2+1
      IF((KDIR.EQ.123).OR.(KDIR.EQ.12).OR.(KDIR.EQ.13))LL=JJ2
      IF(KDIR.EQ.21)LL=KMAX2-JJ2+1
      IF(KDIR.EQ.23)LL=KMAX2+JJ2
      IF(JJ2.LE.8)CDIA(JJ2)=RHC(LL)*2.
      IF((JJ2.LE.8).AND.(KROL.GT.1).AND.((KDIR.EQ.21).OR.(KDIR.EQ.23)))
     1 CDIA(JJ2)=DIA(LL)
      IF(JJ2.GT.8)CDIA(JJ2)=DIA(LL)
 3502 CONTINUE
      NTERM=5
      CALL POLFIT(XA,CDIA,NPT1,NTERM,A,CHISQ1)
      DO 3504 JJ4=1,NPT1
      DDIA(JJ4)=A(1)
      DO 3605 JJJ=2,NTERM
 3604 DDIA(JJ4)=DDIA(JJ4)+A(JJJ)*XA(JJ4)**(JJJ-1)
 3605 CONTINUE
      IF(DDIA(JJ4).LE.0.)DDIA(JJ4)=0.
      IF(JJ4.GE.NPT1-10)DDIA(JJ4)=CDIA(JJ4)
 3504 CONTINUE
      DDIA(1)=DDIA(2)
      IF(JCOUNT.NE.64) GO TO 3603
      IF(ABS(DAY-50.0).GT.0.1.AND.ABS(DAY-49.875).GT.0.1)GO TO 3603
      WRITE(6,3602)(II,CDIA(II),DDIA(II),II=1,NPT1)
 3602 FORMAT(I5,2E15.8)
 3603 DO 3507 JJ5=1,NPT1
      IF((KDIR.EQ.321).OR.(KDIR.EQ.31).OR.(KDIR.EQ.32))LL=KMAX5-JJ5+1
      IF((KDIR.EQ.123).OR.(KDIR.EQ.13).OR.(KDIR.EQ.12))LL=JJ5
      IF(KDIR.EQ.21)LL=KMAX2-JJ5+1
      IF(KDIR.EQ.23)LL=KMAX2+JJ5
      IF(JJ5-KNH) 3505,3505,3506
```

```
 3505 IF((KRCL.GT.1).AND.((KDIR.EQ.21).OR.(KDIR.EQ.23)))GO TO 3506
      RHC(LL)=DDIA(JJ5)/2.
      DIA(LL)=2.*RHC(LL)*SIN(ALPHA(LL))
      TLRHC=RHC(LL)*COS(ALPHA(LL))
      TL(LL)=-TLRHC
      IF(KDIR.EQ.23)TL(LL)=XPOS2-TLRHC
      IF(KDIR.EQ.21)TL(LL)=XPOS2+TLRHC
      IF(KDIR.EQ.32.OR.KDIR.EQ.31.OR.KDIR.EQ.321)TL(LL)=XPOS3+TLRHC
      XL(LL)=2.*RHC(LL)*SIN(DALPHA(LL)/2.)*SIN(ALPHA(LL))
      GO TO 3507
 3506 DIA(LL)=DDIA(JJ5)
 3507 CONTINUE
 3511 KPLOT=KPLOT+1
C     IF(DAY.GE.DAYMAX-.01) GOTO 1131
C     IF(KPLOT.LT.9) GOTO22
C     IF(JCOUNT.NE.64.AND.DAY.LT.DAYMAX-.01) GO TO 22
C     SSS=0.
C     DO 3521 JJ8=1,10
C     SSS=SSS+1.
C     DDAY=36.+SSS*16.
C     IF(ABS(DDAY-DAY).LT.0.05)GO TO 1131
C3521 CONTINUE
C     IF(ABS(DAY-6.).LT.0.1)GO TO 1131
      IF(ABS(DAY-16.0).LT.0.1)GO TO 1131
      IF(ABS(DAY-30.125).LT.0.1)GO TO 1131
C     IF(ABS(DAY-44.0).LT.0.1)GO TO 1131
      IF(ABS(DAY-70.75).LT.0.1)GO TO 1131
      IF(ABS(DAY-90.).LT.0.1)GO TO 1131
      IF(ABS(DAY-106.125).LT.0.1)GO TO 1131
      GO TO 22
 1131 CALL PLTPLN(N,KDIR)
   21 CALL PLT2D(SCFM,DAYLE2)
      CALL PLOT(10.,0.,-3)
C     KPLOT=1
   22 CONTINUE
      GOTO 1217
C
  215 IF(KRCL.GT.1)GOTO1217
C CONVERT HEMISPHERICAL TO CYLINDRICAL GOEMETRY
      NRCL=INT(XMIN2)+KNH+1
      K4=KNH
      DO 1215 K1=1,K4
      KLK=KMAX6-K1+1
      TLT(K1)=TL(KMAX6-K1+1)
      DIAT(K1)=DIA(KMAX6-K1)
C     WRITE(6,8888)K1,KLK,TLT(K1),DIAT(K1)
C8888 FORMAT(2I10,2F20.5)
 1215 CONTINUE
      DO 1216 K2=NRCL,KMAX1
      XL(K2)=DELXL
      TL(K2)=XPOS2-(KMAX1-K2)*DELXL
```

```
      TLAVE=TL(K2)-XL(K2)/2.0
      NPTS=KNH
      NTERMS=4
      CALL INTERP(TLT,DIAT,NPTS,NTERMS,TLAVE,DIA(K2))
C     WRITE(6,8889)I,K2,TLAVE,DIA(K2)
      IF(D2.GT.DIA(K2))DIA(K2)=D2
      KSEAM(K2)=1
      IF(DIA(K2).GE.1.128*SMTK)KSEAM(K2)=2
 1216 CONTINUE
      DIA(KMAX1)=(DIA(KMAX1-1)+DIA(KMAX6+1))/2.0
C CONVERT CYL. TO HEM. GEOMETRY
      DO 218 KH=1,KNH
      K2=KMAX1+KH
      K3=KMAX6+1
      ALPHAR=1.57
      DO 216 K1=K3,KMAX5
      ALPHA1=ATAN(DIA(K1)/2.0/(TL(K1)-XPOS2))
      IF(ALPHA1.LE.ALPHA(K2))GOTO217
      IF(ALPHA1.GT.ALPHAR)GOTO 1218
      ALPHAR=ALPHA1
      K1R=K1
  216 CONTINUE
      GOTO218
 1218 DIA(K2)=DIA(K1R)
      RHC(K2)=DIA(K1R)/2.0/SIN(ALPHA1)
      KSEAM(K2)=KSEAM(K1R)
      GO TO 1219
  217 DIA(K2)=DIA(K1)
      RHC(K2)=DIA(K1)/2.0/SIN(ALPHA1)
      KSEAM(K2)=KSEAM(K1)
 1219 TL(K2)=DIA(K2)/2.0/TAN(ALPHA(K2))+XPOS2
      XL(K2)=2.0*RHC(K2)*SIN(DALPHA(K2)/2.0)*SIN(ALPHA(K2))
      IF(TL(K2).GT.TL(KMAX5))GOTO1220
      GOTO218
 1220 TL(K2)=TL(KMAX5)
      DIA(K2)=DIA(KMAX5)
  218 CONTINUE
      IF(KRCL.EQ.1)GOTO8
   22 CONTINUE
 1217 CALL PLOT(0.,0.,999)
      STOP
      END

 ***** SUBPROGRAMS *****
      SUBROUTINE HMTR(V,P,WM,PR,DD,CPB,POR,X,D,TB,TW,RNU,RE,RA,HMF,HMN,
     *HM)
      TFILM=TB
      GC=32.2*3600.0
      SCH=0.95
      RHOB=P*144.0*WM/(1545.0*TB)
      VISB=7.300E-07*TFILM**0.5/(1.0+189.07/TFILM)*60.0
```

```
      DDX=(DD/P*14.7)*(TFILM/(1.8*300.0))**1.5
      RE=RHOB*V*D/VISB
C * * * FORCED CONVECTION IN THE INJECTION REGION * * *
      GZ=RE*PR*D/X/POR**0.667
      ANUP=-22.2+6.08*ALOG(GZ)
      IF(GZ.LT.100)ANUP=5.80
      IF(GZ.GT.10000.)ANUP=33.4
      ANUF=ANUP*RNU
      HMF=ANUF*(DDX/D)*(SCH/PR)**0.333*POR**.667
C     DIVIDING BY 50 "CORRECTS" HMF SINCE D IS DPOR AND NOT DIA(K)
C     THIS IS EQUIVALENT TO SETTING HMF=0
      HMF=HMF/50.
C * * * NATURAL CONVECTION IN THE INJECTION REGION * * *
      RA=((RHOB**2)*GC/TFILM)*ABS(TW-TB)*(D**3*PR/VISB**2)/POR**0.667
      IF(RA.LE.10**4)GOTO10
      ANUN=0.15*RA**0.25
      GO TO 6
   10 ANUN=1.67*RA**0.167
    6 HMN=ANUN*(DDX/D)*(SCH/PR)**0.333*POR**.667
C     RA=0.0
C     HMN=0.0
      HM=(HMF**2+HMN**2)**0.5
      RETURN
      END
      SUBROUTINE INTERP (X,Y,NPTS,NTERMS,XIN,YOUT)
      DOUBLE PRECISION DELTAX,DELTA,A,PROD,SUM
      DIMENSION X(16),Y(16),DELTA(10),A(10)
C
C          SEARCH FOR APPROPRIATE VALUE OF X
C
   11 DO 19 I=1,NPTS
      IF(XIN-X(I))13,17,19
   13 I1=I-NTERMS/2
      IF(I1)15,15,21
   15 I1=1
      GOTO21
   17 YOUT=Y(I)
   18 GOTO61
   19 CONTINUE
      I1=NPTS-NTERMS+1
   21 I2=I1+NTERMS-1
      IF(NPTS-I2)23,31,31
   23 I2=NPTS
      I1=I2-NTERMS+1
   25 IF(I1)26,26,31
   26 I1=1
   27 NTERMS=I2-I1+1
C
C          EVALUATE DEVIATIONS DELTA
C
   31 DENOM=X(I1+1)-X(I1)
```

```
      DELTAX=(XIN-X(I1))/DEN
      DO 35 I=1,NTERMS
      IX=I1+I-1
   35 DELTA(I)=(X(IX)-X(I1))/DEN
C
C           ACCUMULATE COEFFICIENTS A
C
   40 A(1)=Y(I1)
   41 DO 50 K=2,NTERMS
      PROD=1.0
      SUM=0.0
      IMAX=K-1
      IXMAX=I1+IMAX
      DO 49 I=1,IMAX
      J=K-I
      PROD=PROD*(DELTA(K)-DELTA(J))
   49 SUM=SUM-A(J)/PROD
   50 A(K)=SUM+Y(IXMAX)/PROD

           ACCUMULATE SUM OF EXPANSION

   51 SUM=A(1)
      DO 57 J=2,NTERMS
      PROD=1.0
      IMAX=J-1
      DO 56 I=1,IMAX
   56 PROD=PROD*(DELTAX-DELTA(I))
   57 SUM=SUM+A(J)*PROD
   60 YOUT=SUM
   61 RETURN
      END
      SUBROUTINE POLFIT(X,Y,NPTS,NTERMS,A,CHISQR)
      DOUBLE PRECISION SUMX,SUMY,XTERM,YTERM,ARRAY,CHISQ
      DIMENSION X(NPTS),Y(NPTS),A(5),SUMX(19),SUMY(10),
     1ARRAY(10,10)
   11 NMAX=2*NTERMS-1
      DO 13 N=1,NMAX
   13 SUMX(N)=0.
      DO 15 J=1,NTERMS
   15 SUMY(J)=0.
      CHISQ=0.
   21 DO 50 I=1,NPTS
      XI=X(I)
      YI=Y(I)
   37 WEIGHT = 1.
      IF(XI.EQ.1.) WEIGHT=0.
   41 XTERM = WEIGHT
      DO 44 N=1,NMAX
      SUMX(N) = SUMX(N) + XTERM
   44 XTERM = XTERM * XI
   45 YTERM = WEIGHT * YI
```

```
      DO 48 N=1,NTERMS
      SUMY(N) = SUMY(N) + YTERM
   48 YTERM = YTERM * XI
   49 CHISQ =CHISQ + WEIGHT*YI**2
   50 CONTINUE
C     CONSTRUCT MATRICIES AND CALCULATE COEFFICIENTS
   51 DO 54 J=1,NTERMS
      DO 54 K=1,NTERMS
      N = J + K - 1
   54 ARRAY(J,K) = SUMX(N)
      DELTA = DETERM (ARRAY, NTERMS)
      IF (DELTA) 61, 57, 61
   57 CHISQR = 0.
      DO 59 J=1, NTERMS
   59 A(J) = 0.
      GO TO 80
   61 DO 70 L=1, NTERMS
   62 DO 66 J=1, NTERMS
      DO 65 K=1, NTERMS
      N = J + K - 1.
   65 ARRAY(J,K) = SUMX(N)
   66 ARRAY(J,L) = SUMY(J)
   70 A(L) = DETERM (ARRAY, NTERMS) / DELTA
C     CALCULATE CHI SQUARE
   71 DO 75 J=1, NTERMS
      CHISQ = CHISQ - 2.*A(J)*SUMY(J)
      DO 75 K=1, NTERMS
      N = J + K - 1
   75 CHISQ = CHISQ + A(J)*A(K)*SUMX(N)
   76 FREE = NPTS - NTERMS
   77 CHISQR = CHISQ / FREE
   80 RETURN
      END
      FUNCTION DETERM (ARRAY,NORDER)
      DOUBLE PRECISION ARRAY,SAVE
      DIMENSION ARRAY(10,10)
C     CALCULATE THE DETERMINANT OF A SQUARE MATRIX
C     NORDER - ORDER OF DETERMINANT (DEGREE OF MATRIX)
C     THIS SUBPROGAM DESTROYS THE INPUT MATRIX ARRAY
C     DIMENSION STATEMENT VALID FOR NORDER UP TO 10
   10 DETERM=1.
   11 DO 50 K=1,NORDER
C     INTERCHANGE COLUMNS IF DIAGONAL ELEMENT IS ZERO
      IF (ARRAY(K,K))  41, 21, 41
   21 DO 23 J=K, NORDER
      IF (ARRAY(K,J)) 31, 23, 31
   23 CONTINUE
      DETERM = 0.
      GO TO 60
   31 DO 34 I=K, NORDER
      SAVE = ARRAY(I,J)
```

```
      ARRAY(I,J) = ARRAY(I,K)
   34 ARRAY (I,K) = SAVE
      DETERM = - DETERM
C     SUBTRACT ROW K FROM LOWER ROWS TO GET DIAGONAL MATRIX
   41 DETERM = DETERM * ARRAY(K,K)
      IF (K- NORDER) 43, 50, 50
   43 K1 = K + 1
      DO 46 I=K1, NORDER
      DO 46 J=K1, NORDER
   46 ARRAY(I,J) = ARRAY(I,J) - ARRAY(I,K) * ARRAY(K,J)/ARRAY(K,K)
   50 CONTINUE
   60 RETURN
      END
      SUBROUTINE PLTBKG
C     CALL SYMBOL(4.3,7.15,.300,'PRICETOWN I',0.,11)
      CALL SYMBOL(2.5,5.4,.140,'D OR W',0.,6 )
      CALL SYMBOL(2.5,5.1,.140,'(FT)',0.,4 )
      CALL SYMBOL(4.8,6.7,.200,' RCL  ',0.,6)
      CALL SYMBOL(7.5,6.7,.200,'DAY=',0.,4)
      CALL SYMBOL(3.8,6.3,.100,'P/I-1',0.,5)
      CALL SYMBOL(6.8,6.3,.100,'P/I-2',0.,5)
      CALL SYMBOL(9.05,6.3,.100,'P/I-3',0.,5)
      CALL SYMBOL(2.8,4.0,.100,'SEAM',0.,4)



      CALL WAXHT(0.1,0.1)
      CALL AXIS(3.8,2.0,' ',0 ,4.0,90.,-40.,20.,-5.)
      CALL AXIS(6.8,2.0,' ',0,4.0,90.,-40.,20.,-5.)
      CALL AXIS(9.05,2.0,' ',-0,4.0,90.,-40.,20.,-5.)
      CALL AXIS(2.8,1.5,'L(FT)',-5,7.0,0.,-20.,20.,10.)
      CALL PLOT(2.8,4.175,3)
      CALL AROHD(2.8,4.775,2.8,4.175,0.3,0.1,11)
      CALL PLOT(2.8,3.825,3)
      CALL AROHD(2.8,3.225,2.8,3.825,0.3,0.1,11)
      CALL PLOT(2.8,3.825,3)
      CALL DASHPT(9.8,3.825,0.05)
      CALL PLOT(2.8,4.175,3)
      CALL DASHPT(9.8,4.175,0.05)
      RETURN
      END
      SUBROUTINE PLTPLN(N,KDIR)
      CALL SYMBOL(4.3,7.15,.300,'PRICETOWN I',0.,11)
      CALL SYMBOL(2.3,5.4,.140,'W',0.,1 )
      CALL SYMBOL(2.1,5.1,.140,'(FT)',0.,4 )
      CALL SYMBOL(4.8,6.7,.200,'PHASE:',0.,6)
      CALL SYMBOL(7.5,6.7,.200,'DAY=',0.,4)
      CALL SYMBOL(3.8,6.3,.100,'P/I-1',0.,5)
      CALL SYMBOL(6.8,6.3,.100,'P/I-2',0.,5)
      CALL SYMBOL(9.05,6.3,.100,'P/I-3',0.,5)
      CALL SYMBOL(5.1,6.7,.200,'CLE',0.,3)
```

```
      CALL SYMBOL(2.0,4.0,.100,'SEAM',0.,4)
C     IF(N.EQ.0) CALL SYMBOL(5.4,6.7,.200,'RCL',0.,3)
C     IF(N.GT.0) CALL SYMBOL(5.4,6.7,.200,'CLE',0.,3)
C     IF((N.EQ.48).AND.(KDIR.EQ.23)) CALL SYMBOL(5.4,6.7,.200,'CLE',0.,3)
C     IF((N.GT.48).AND.(KDIR.EQ.12)) CALL SYMBOL(5.4,6.7,.200,'RCL',0.,3)
C
      CALL SYMBOL(4.30,4.00,.100,'M1 +',0.,4)
      CALL SYMBOL(5.08,3.39,.100,'M2 +',0.,4)
      CALL SYMBOL(5.85,4.25,.100,'M3 +',0.,4)
      CALL SYMBOL(7.28,3.88,.100,'M4 +',0.,4)
      CALL SYMBOL(3.73,3.93,.140,'+',0.,1)
      CALL SYMBOL(6.73,3.93,.140,'+',0.,1)
      CALL SYMBOL(8.98,3.93,.140,'+',0.,1)
C
C
C     CALL WAXHT(0.1,0.1)
      CALL AXIS(2.8,2.0,' ',0 ,4.0,90.,-40.,20.,-5.)
C     CALL AXIS(8.7,2.0,' ',0,4.0,90.,-40.,20.,-5.)
C     CALL AXIS(8.95,2.0,' ',0,4.0,90.,-40.,20.,-5.)
      CALL AXIS(2.8,1.5,'L(FT)',-5,7.0,0.,-20.,20.,10.)
      CALL PLOT(2.2,4.05,3)
C     CALL AROHD(2.2,4.175,2.2,4.775,0.3,0.1,11)
      CALL PLOT(2.2,3.975,3)
C     CALL AROHD(2.2,3.825,2.2,4.425,0.3,0.1,11)
      CALL PLOT(1.9,3.825,3)
      CALL DASHPT(2.5,3.825,0.05)
      CALL PLOT(1.9,4.175,3)
      CALL DASHPT(2.5,4.175,0.05)
      RETURN
      END
      SUBROUTINE PLT2D(SCFM,DAYLE2)
      COMMON N,KI,TL(137),DIA(137),DIP(137),DIN(137),TLP(137),DAY,KDIR
     *  ,ALPHA(137),DALPHA(137),XL(137),RHC(137),KSEAM(137)
C
      K2=68
      K3=85
C
      K1=1
      IF(DAY.LE.DAYLE2+.01)K1=77
      DO 33 L =K1,KI
      TLP(L)=TL(L)/20.0
      DIN(L)=DIA(L)/5.00/8.
      DIP(L)=-DIN(L)
   33 CONTINUE
C
      CALL NUMBER(8.4,6.7,.200,DAY,0.,1)
C
      CALL PLOT(3.8,4.,-3)
      CALL PLOT(TLP(K1),DIN(K1),3)
      DO 30 L=K1,KI
      IF((L.GT.K2).AND.(L.LT.K3).AND.(DAY.GT.DAYLE2+.01))GOTO30
```

```
      CALL PLOT(TLP(L),DIN(L),2)
   30 CONTINUE
      CALL PLOT(TLP(K1),DIN(K1),3)
      DO 31 L=K1,KI
      IF((L.GT.K2).AND.(L.LT.K3).AND.(DAY.GT.DAYLE2+.01))GOTO31
      CALL PLOT(TLP(L),DIP(L),2)
   31 CONTINUE
C     CALL PLOT(TLP(KI),DIN(KI),3)
C     CALL PLOT(TLP(KI),DIP(KI),2)
      CALL PLOT(-3.8,-4.,-3)
      IF(KDIR.EQ.123) GOTO 70
      IF((KDIR.EQ.12).OR.(KDIR.EQ.13)) GOTO 10
      IF((KDIR.EQ.21).OR.(KDIR.EQ.23)) GOTO 35
      IF((KDIR.EQ.31).OR.(KDIR.EQ.32)) GOTO 50
   10 CALL PLOT(3.8,5.9,3)
      CALL AROHD(3.8,5.3,3.8,5.9,0.3,0.1,11)
      CALL SYMBOL(4.1,5.3,.100,'SCFM',0.,4)
      CALL NUMBER(4.0,5.5,.100,SCFM,0.,0)
      IF(KDIR.EQ.13) GOTO 20
      CALL PLOT(6.8,5.3,3)
      CALL AROHD(6.8,5.9,6.8,5.3,0.3,0.1,11)
      GOTO 100
   20 CALL PLOT(9.05,5.3,3)
      CALL AROHD(9.05,5.9,9.05,5.3,0.3,0.1,11)
      GOTO 100
   35 CALL PLOT(6.8,5.9,3)
      CALL AROHD(6.8,5.3,6.8,5.9,0.3,0.1,11)
      CALL SYMBOL(7.1,5.3,.100,'SCFM',0.,4)
      CALL NUMBER(7.0,5.5,.100,SCFM,0.,0)
      IF(KDIR.EQ.23) GOTO 40
      CALL PLOT(3.8,5.3,3)
      CALL AROHD(3.8,5.9,3.8,5.3,0.3,0.1,11)
      GOTO 100
   40 CALL PLOT(9.05,5.3,3)
      CALL AROHD(9.05,5.9,9.05,5.3,0.3,0.1,11)
      GOTO 100
   50 CALL PLOT(9.05,5.9,3)
      CALL AROHD(9.05,5.3,9.05,5.9,0.3,0.1,11)
      CALL SYMBOL(9.25,5.3,.100,'SCFM',0.,4)
      CALL NUMBER(9.25,5.5,.100,SCFM,0.,0)
      IF(KDIR.EQ.32) GOTO 60
      CALL PLOT(3.8,5.3,3)
      CALL AROHD(3.8,5.9,3.8,5.3,0.3,0.1,11)
      GOTO 100
   60 CALL PLOT(6.8,5.3,3)
      CALL AROHD(6.8,5.9,6.8,5.3,0.3,0.1,11)
      GOTO 100
   70 CALL PLOT(3.8,5.9,3)
      CALL AROHD(3.8,5.3,3.8,5.9,0.3,0.1,11)
      CALL SYMBOL(4.1,5.3,.100,'SCFM',0.,4)
      CALL NUMBER(4.0,5.5,.100,SCFM,0.,0)
```

```
      CALL PLOT(6.8,5.3,3)
      CALL AROHD(6.8,5.9,6.8,5.3,0.3,0.1,11)
      CALL PLOT(9.05,5.3,3)
      CALL AROHD(9.05,5.9,9.05,5.3,0.3,0.1,11)
  100 RETURN
      END
```

5.8 FG Model Computer Program: FGLS21

```
  PROGRAM FGLS21(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE2)
D. PROG. FGPL13,FGN27E,FGN40E,FGN48E,FGN50P,FGL1P,FGLK20 & FGLK65

*****************************************************************
*** THIS PROGRAM IS SAVED UNDER...PCLEF43  (OLD FORD14B)...*****
  THIS VERSION SOLVES FOR TW + TBKMN SIMULTANEOUSLY AS F(GRAD)
  THIS VERSION CONTAINS MOD. IN AIR/OX MASS FLOW + ENERGY BAL EQNS
  PROGRAM: UCG MODEL IIIC WITH CONVECTIVE AND RADIATIVE ENERGY
  BALANCES.  ALL CALCULATIONS ARE IN UNITS OF FT,LBM,MIN,BTU,R.
  INPUT AND OUTPUT VALUES ARE CONVERTED BEFORE CALCULATIONS
    OR PRINTOUT,RESPECTIVELY.
  PRESSURES ARE IN PSIA, ALL VELOCITIES ARE IN FT/MIN
  DIMENSION IBUF(512),XI(125),CDIA(125), DDIA(125),A(5)
  COMMON N,TL(125),DIA(125),DIP(125),DIN(125),TLP(125),DAY,KDIR
 *,ALPHA(125),DALPHA(125),XL(125),RHC(125),KSEAM(125),ALPHN(125)
 *,RNU(125),TLX(122),DIAX(122),KSMLZ(122),NDAY,DAYMAX,DIAL(122)
  DIMENSION F(125,125),CIRC(125),TO(150),TI(150),
 *TWB(125),TB1(125),TW1(125),FOFTI(150),DLZ(125),ALPHAT(8),RHCLE(8)
  CALL LIMITS(11.5,7.625,0.0,0.0)

***  LIST OF PROGRAM VARIABLES  *****

  N=27
  DELTAT= 3.00
  DAYMAX=11.750
  DAY=0.0
  DAYJ1=DAY
  DAYJ2=0.
  DAYJ0=266.625
  KDIR=123

 OPTICALLY THICK RAD SET NTHICK = 1,  IF OPTICALLY THIN: NTHICK=2
  NTHICK=2
    RC/O OR GAMMA REACT. MUST BE GIVEN FOR THIS PROGRAM TO WORK.
    IF GAMMA EXCESS OR GAMMA TOTAL ARE GIVEN, MUST MODIFY PROGRAM
    TO INCLUDE SOLUTION OF COAL & ENERGY EQNS. TO OBTAIN GMR & RCO2 AT EACH
  GMR=0.
  GMXS=0.
  GMT=0.0000
 ** ENTER TONS COAL CONSUMED DURING LINKING IF WANT LINK + GAS.
 IS VOL. MAT., CHC IS CHAR, CC IS COAL CONS, & CAFF IS COAL AFFECTED (TONS)
  VMC=146.08
  CHC=0.0
  CC=146.08
 ** MODIFY TEMPERATURES AS NECESSARY. TREF=TCOAL IS TAKEN AT 537R.
   IF SET TREF AT TCOAL, OBTAIN NEGLIGIBLE ERROR IN CHEM. & LATENT ENERGIES.
  TREF=537.0
  TREFCL=537.0
  TREFCH=1510.0
  TAIR=537.
  TWALL=2400.
```

```
      TVOL=1000.
      TLZ1=1500.
      DELT=50.
      DNC=0.0500
      DZCH=2.04
      TLMAX=104.0
C
C ***** LIST OF COAL PROPERTIES *****
C
      BMRMX=0.6950
      SMTK1=7.00
      YC=0.7206
      YH=0.0482
      YS=0.04292
      YOX=0.05235
      YMOIST=0.01362
      YASH=0.1215
      YVM=0.3808
      YFC=1.0-YVM-YMOIST-YASH
      RCHNR=0.8
      SMTK=SMTK1*(1-YASH-RCHNR*YFC)
      RHOC=79.29
      POR=YVM
C
C ***** LIST OF PROGRAM CONSTANTS *****
C
      SIGM = 2.85E-11
      CIRCT1=12.00
      PI=3.1416
      BMW=29.0
      AIRMW=29.0
      SCH=0.95
      RHOAS=.075
      WO2=0.23
      PR=0.8
      DO=.0139
      GC=32.2*3600.
      CPCO=0.287
      CPH2=3.618
      CPH2O=0.560
      CPSO2=0.2
      CPASH=0.270
      CPS=0.190
      CPN2=0.283
      CPCO2=0.298
      CPAIR=0.276
      CPGAS=CPAIR
      CPO2=0.263
      CPCOAL=0.240
      HCCO=-3960.0
      HCCO2=-14100
```

```
      HCH2O=-51623.0
      HCSO2=-3980.0
      HRWG=4703.0
      HSLS=15.4
      HSLASH=90.0
      HFGH2O=1050.3
C
C ***** INITIAL CALCULATIONS *****
C
      GMMN=YOX/32.*2.*18.+YMOIST
C * * * CALCULATION OF ANGLES IN HEMISPHERE REGION * * *
C
      KNH=16
      KMAX=KNH+1
      KD=KMAX+1
      DO 23 K=1,KNH
      DALPHA(K)=3.1416/2.0/KNH
      FK=K
      FKNH=KNH
      FNK=FK/FKNH
      ALPHN(K)=(3.1416/2.0)*FNK
      READ(5,24) ALPHA(K),RNU(K)
   24 FORMAT(F6.4,3X,F5.3)
C 601 WRITE(6,602) ALPHA(K),RNU(K),ALPHN(K),DALPHA(K)
  602 FORMAT(2X,'ALPHA(K)    RNU(K)    ALPHN(K)    DALPHA(K)'/2X,F6.4,6X,F_
     *5.3,6X,F6.4,6X,F6.4)
   23 CONTINUE
;
;     READ IN ENHANCED LINK ZONE GEOMETRY
;
      READ(5,9504)NDPTS
 9504 FORMAT(I5)
      READ(5,1717)(TLX(L),DIAX(L),L=1,NDPTS)
 1717 FORMAT(F7.2,1X,F6.2)
;
; ***** SET INITIAL CONDITIONS *****
;
      DO 11 K=1,122
   11 DIAL(K)=DIAX(K)
      DO 9 K=1,125
      RHC(K)=0.0
      DLZ(K)=0.
      TW1(K)=TWALL
      TB1(K)=TAIR
      TWB(K)=537.
      CIRC(K)=0.0
    9 KSEAM(K)=1
      READ(5,32)DAYJ1,DURA,RCO1,SCFM,P,KDIR,FCHR,RCHO2,RVMO2,GCHR,COCO2
      DAYJ2=DAYJ1+DURA-DAYJ0+.1
      WRITE(6,6551)DAYJ1,DURA,RCO1,SCFM,P,KDIR
```

```
C * * * EXCESS WATER, GAMMA REACTING OR RCO2 CALCULATION * * *
C       RC/O OR GAMMA REACT. MUST BE GIVEN FOR THIS PROGRAM TO WORK.
C       IF GAMMA EXCESS OR GAMMA TOTAL ARE GIVEN, MUST MODIFY PROGRAM
C       TO INCLUDE SOLUTION OF COAL & ENERGY EQNS. TO OBTAIN GMR & RCO2 AT EACH
      IF(GMXS.GT.0.0) STOP
      IF(GMT.GT.0.0) STOP
      RCO2=RCO1/(1+(YC-YFC)/YC*(1-FCHR)/FCHR)
      IF(RCO2.GT.0.0)GMR=1.5*YC*(1.-1./RCO2/(1.333*YC+8.*YH+YS-YOX))
      IF(GMR.LT.0)GMR=0
      FWG=GMR/1.5/YC
      FOX=1.0-FWG
      GMT=GMR+FWG*(1.125*YOX+YMOIST)
C UNCOMMENT THE FOLLOWING LINE IF GMR IS THE INDEPENDENT VARIABLE
C     RCO2=1.0/FOX/(1.333*YC+8.0*YH+YS-YOX)
      FWGCH=GCHR/1.5
      FOXCH=1.-FWGCH
      GMRCH=GCHR*YFC
C
C  ***** GMXS BELOW EXCLUDES WATER IN COAL VIA MOIST OR FORMATION
C
      GMXS=GMT-(YMOIST+FOX*9*YH+FWG*1.125*YOX)
      IF(GMXS.LT.0.0)GMXS=0.0
C4029 WRITE(6,4030) GMMN,GMR,GMT,GMXS,RCO2
 4030 FORMAT(6X,'GAMMA MIN',4X,' GAMMA REACT',4X,'GAMMA TOTAL',
     *3X,'GAMMA EXCESS',10X,'RC/C'/ 5F15.3,/)
   15 WRITE(6,5)DAY,DAYJ1,DURA,SCFM,RCO1,SMTK,P,DELTAT,RHOC,POR,N
     *,NTHICK,RVMO2,RCHO2,FCHR,GMR,GMXS,GMRCH,GCHR,FOXCH,FWGCH,KDIR,RCO2
     *,COCO2
C
C *****  INITIAL INJECTION REGION CAVITY BURN (1ST TIME INTERVAL) *****
C
      WRITE(6,50)
   50 FORMAT(//,2X,'I  K  DAY  XMIN  TL(K)  D(K)  FLMBL FLMOY FLMOL CAF
     *F   WOX',/)
      I=1
      FLRMA=RHOAS*SCFM
      FLRMBL=FLRMA*(1+(RCHO2+RVMO2)*WO2)
      FLRMOY=0.0
      FLRMOL=0.0
      VHC1=(RCHO2*WO2*FLRMA)/(RHOC*YFC)*DELTAT*60.
      RHC1=(VHC1/5.24)**0.333
      CHC=CHC+RCHO2*FLRMA*WO2*DELTAT*60/2000
      CC=VMC+CHC
      CAFF=VMC/YVM
      WOX=WO2
      DAY=DAY+DELTAT/24.0
C
C * * * CALCULATION OF INITIAL CAVITY SHAPE DIMENSIONS * * *
C
      XMIN=-RHC1
      DO 38 KK=1,8
```

```
      ALPHAT(KK)=ATAN(-DIAX(KK)/2./TLX(KK))
   38 RHCLE(KK)=SQRT(TLX(KK)**2+(DIAX(KK)/2)**2)
      DO 40 K=1,KNH
      RHC(K)=RHC1
C
C ***** TL IS DIST. TO CENTER OF SUB-SECTOR AREA
C ***** XL IS THE PROJECTION OF SUB-SECTOR WALL AREA ON AXIS
C
  440 TL(K)=-RHC(K)*COS(ALPHA(K))
      XL(K)=2.*RHC(K)*SIN(DALPHA(K)/2.)*SIN(ALPHA(K))
      DIA(K)=2.*RHC(K)*SIN(ALPHA(K))
      NPTS=8
      NTERMS=3
      CALL INTERP(ALPHAT,RHCLE,NPTS,NTERMS,ALPHA(K),DLZ(K))
      WRITE(6,97) I,K,DAY,XMIN,TL(K),DIA(K),FLRMBL,FLRMOY,FLRMDL,CAFF
     *,WO2
   97 FORMAT(I3,1X,I2,1X,F4.2,1X,F6.2,1X,F6.2,1X,F5.2,1X,F6.2,2F6.2,
     *F6.0,F6.3,/)
   40 CONTINUE
C     WRITE(6,9515)(DLZ(M),M=1,16)
 9515 FORMAT(5X,F10.3)
      K=KNH+1
      XL(K)=RHC1
      TL(K)=RHC1
      DIA(K)=DIA(K-1)
      TLAV=TL(K)-RHC1/2.0
      NTERMS=4
      CALL INTERP(TLX,DIAX,NDPTS,NTERMS,TLAV,DLZ(K))
      WRITE(6,97) I,K,DAY,XMIN,TL(K),DIA(K),FLRMBL,FLRMOY,FLRMDL,CAFF
     *,WO2
      WRITE(6,540)VMC,CHC,CC,CAFF
  540 FORMAT(/,2X,'VM TONS  =',F8.2,2X,'CHAR TONS=',F8.2,2X,'COAL CONS='
     1  ,F8.2,2X,'COAL AFFECTED=',F8.2)
      WRITE(6,9514)(TLX(K),DIAX(K),TL(K),DLZ(K),K=1,KNH+1)
 9514 FORMAT(4(5X,F10.3))

 ***** ENTER TIME INTERVALS AND FLOW SCHEDULE *****

      CALL PLOTS(IBUF,512,2,50)
      DO 22 I=2,N
      SFN=0.0
      TW1(KMAX)=TW1(KMAX-1)
      TBKMN=2200.
      IF(I.GT.2)DELTAT= 6.0
      IF(I.GT.9)DELTAT= 12.0
      IF(I.GT.13)DELTAT= 18.0
      IF(I.GT.14)DELTAT= 6.0
      IF(I.GT.15)DELTAT= 12.0
      IF(I.GT.17)DELTAT= 18.0
      IF(I.GT.18)DELTAT= 6.0
      IF(I.GT.19)DELTAT= 18.0
```

```
      IF(I.GT.20)DELTAT= 6.0
      IF(I.GT.21)DELTAT= 18.0
      IF(I.GT.22)DELTAT= 6.0
      IF(I.GT.23)DELTAT= 24.0
      IF(I.GT.25)DELTAT= 18.0
      DAY=DAY+DELTAT/24.0
      NDAY=DAY-0.01
      IF(DAY.GT.DAYMAX+.01 )GOTO130
   31 IF(DAY.LT.DAYJ2)GO TO 35
      READ(5,32)DAYJ1,DURA,RCO1,SCFM,P,KDIR,FCHR,RCHO2,RVMO2,GCHR,COCO2
   32 FORMAT(2X,3F7.3,F10.2,F9.3,I5,F9.5,4F6.3)
      DAYJ2=DAYJ1+DURA-DAYJ0+.1
C
C * * * EXCESS WATER, GAMMA REACTING OR RCO2 CALCULATION * * *
C
      RCO2=RCO1/(1+(YC-YFC)/YC*(1-FCHR)/FCHR)
      IF(RCO2.GT.0.0)GMR=1.5*YC*(1.-1./RCO2/(1.333*YC+8.*YH+YS-YOX))
      IF(GMR.LT.0)GMR=0
      FWG=GMR/1.5/YC
      FOX=1.0-FWG
      GMT=GMR+FWG*(1.125*YOX+YMOIST)
C UNCOMMENT THE FOLLOWING LINE IF GMR IS THE INDEPENDENT VARIABLE
C     RCO2=1.0/FOX/(1.333*YC+8.0*YH+YS-YOX)
      FWGCH=GCHR/1.5
      FOXCH=1.-FWGCH
      GMRCH=GCHR*YFC
C
C  ***** GMXS BELOW EXCLUDES WATER IN COAL VIA MOIST OR FORMATION
C
      GMXS=GMT-(YMOIST+FOX*9*YH+FWG*1.125*YOX)
      IF(GMXS.LT.0.0)GMXS=0.0
C4031 WRITE(6,4030) GMMN,GMR,GMT,GMXS,RCO2
   35 FLRMA=RHOAS*SCFM
C     WRITE(6,6551)DAYJ1,DURA,RCO1,SCFM,P,KDIR
 6551 FORMAT(/,5(3X,F10.3),I10,/)
C     WRITE(6,7005) NTHICK
 7005 FORMAT(5X,'IF OPT THICK, NTHICK=1, NTHICK=',I4,/
     1 ,1X,'  I  K  NII  NI  S CH  TBIN  TBKMN  TBOUT    TW',
     2 '    TWB  QCONV QCONVB  QRAD  QRADB QRADTK QRADBTK',
     3 '    A1     A4     A2     A3   TWNI')
      IF(ABS(DAY+0.02-NDAY).GE.1.0) GOTO510
      IF(DAY.GE.DAYMAX-.01)GOTO510
      GOTO 499
  510 WRITE(6,5)DAY,DAYJ1,DURA,SCFM,RCO1,SMTK,P,DELTAT,RHOC,POR,N
     *,NTHICK,RVMO2,RCHO2,FCHR,GMR,GMXS,GMRCH,GCHR,FOXCH,FWGCH,KDIR,RCO2
     *,COCO2
    5 FORMAT(/,T10,'DAY    =',F10.2,T30,'DAYJ1 =',F10.3,T50,'DURATN=',
     * F10.3,/,T10,'SCFM   =',F10.2,T30,'RCO1  =',F10.2,T50,'SM THK=',
     *F10.2,/,T10,'P      =',F10.2,T30,'DELTAT=',F10.2,T50,'RHOC   =',
     *F10.2,/,T10,'PORSTY=',F10.2,T30,'N INT =',I8,T50,'OPT TK IF 1:',I4
     *,/,T10,'R(VM/O)=',F10.3,T30,'R(CH,R/O)=',F7.3,T50,'F(CH,R)=',F10.3
```

```
     *,/,T10,'GAM REACT=',F7.3,T30,'GAM EXS=',F10.3,T50,'GAM REACT,CH=',
     * F8.3,/,T10,'GAM CH,R=',F9.3,T30,'FOX,CH =',F10.3,T50,'FWG,CH =',
     * F10.3,/,T10,'KDIR   =',I10,T30,'RCO2  =',F10.3,T50,'CO/CO2 =',
     *  F10.3,/)
      WRITE(6,500)DAY,SMTK
  500 FORMAT(T10,'DAY = ',F10.3,T30,'SEAM THICKNESS = ',F5.2,' FT')
      WRITE(6,51)
   51 FORMAT(2X,'I  K   FN    TL(K)  D(K)  FLMBL FLMOY FLMOL  CHC   W
     *OX   RE NO     RA NO   HNATL HTOTL FLRBT  GOXW  S  KCH SCFM  TWALL
     * TBULK DCIRC',/)
   499 CONTINUE
C
C K LOOP     K LOOP      K LOOP      K LOOP
C
      NIII=1
    46 DO 7 K=1,KMAX
      NII=NIII
      IF(K.GT.1)TW1(K)=TW1(K-1)
      KCHR=2
      IF(K.GT.KNH) RNU(K)=1.
C THE FOLLOWING SETS RHC(1)=RHC(2), ETC.
C     IF(K-3) 4001,4000,4001
C4000 RHC(1)=RHC(2)
C     DIA(1)=2.*RHC(1)*SIN(ALPHA(1))
C     XMIN=-RHC(1)
C     TL(1)=-RHC(1)*COS(ALPHA(1))
C     XL(1)=2.*RHC(1)*SIN(DALPHA(1)/2.)*SIN(ALPHA(1))
C     SL=DALPHA(1)*RHC(1)+DALPHA(2)*RHC(2)/2.
 4001 IF(KSEAM(K).EQ.2) GO TO 411
C
C    IF CIRC AREA #SQ AREA=SMTK**2, I.E. DIA#SQRT(4/PI)SMTK GO TO
C     THIN SEAM
C
      IF(DIA(K)-1.128*SMTK)405,401,401
C
C * * * THIN SEAM (KSEAM=2) RELATIONS * * *
C
  401 KSEAM(K)=2
      DIA(K)=(PI*DIA(K)**2/4.)/SMTK
      IF(K.LE.KNH) RHC(K)=DIA(K)/(2.*SIN(ALPHA(K)))
      IF(K.GT.KNH) RHC(K)=DIA(K)/2.
  411 AS=SMTK*DIA(K)
      IF(K.LE.KNH) AS=SMTK*RHC(K)*2.0
      IF(K.LE.KNH) AW=2.0*(SMTK*RHC(K)*DALPHA(K)+DIA(K)*XL(K))
      IF(K.GT.KNH)AW=2.0*(SMTK*XL(K)+DIA(K)*XL(K))
      IF(K.LE.KNH) WFRCT=2.*SMTK*RHC(K)*DALPHA(K)/AW
      IF(K.GT.KNH)WFRCT=2.0*SMTK*XL(K)/AW
      HEIGHT=SMTK
      CHLNTH=2.0*SMTK+DIA(K)
      IF(DIA(K)/SMTK.GE.3) CHLNTH=4.0*SMTK+DIA(K)
      IF(DIA(K)/SMTK.GE.5) CHLNTH=6.0*SMTK+DIA(K)
```

```
      IF(DIA(K)/SMTK.GE.7) CHLNTH=8.0*SMTK+DIA(K)
      IF(DIA(K)/SMTK.GE.9) CHLNTH=10.0*SMTK+DIA(K)
      IF(K.LE.KNH)CHLNTH=2.0*(SMTK+RHC(K))
      IF((K.LE.KNH).AND.(2*RHC(K)/SMTK.GE.3)) CHLNTH=2.*(2.*SMTK+RHC(K))
      IF((K.LE.KNH).AND.(2*RHC(K)/SMTK.GE.5)) CHLNTH=2.*(3.*SMTK+RHC(K))
      IF((K.LE.KNH).AND.(2*RHC(K)/SMTK.GE.7)) CHLNTH=2.*(4.*SMTK+RHC(K))
      IF((K.LE.KNH).AND.(2*RHC(K)/SMTK.GE.9)) CHLNTH=2.*(5.*SMTK+RHC(K))
      GOTO423
C
C * * * THICK SEAM (KSEAM=1) RELATIONS * * *
C
  405 CONTINUE
      WFRCT=1.0
      IF(K.GT.KNH) GO TO 404
C
C
C * * * FOR THICK SEAM IN HEMISPHERE(KSEAM=1 + K.LE.KNH) * * *
      AW=PI*DIA(K)*RHC(K)*DALPHA(K)
      HEIGHT=2.*RHC(K)
      CHLNTH=PI*RHC(K)+2.*RHC(K)
      GO TO 423
C
C * * * FOR THICK SEAM IN STEP-CYL. REG.(KSEAM=1 + K.GT.KNH) * * *
C
  404 AW=PI*DIA(K)*XL(K)
      AS=PI*DIA(K)**2/4.
      HEIGHT=DIA(K)
      RHC(K)=DIA(K)/2.
      CHLNTH=PI*DIA(K)/2.0+DIA(K)
  423 IF(K.GT.1) GOTO902
C
C * * * FOR K=1 * * *
C
C     TB1(K)=960.0
      FLRMAR=FLRMA/2.0*(1.0-COS(ALPHN(K)))
      FLRMBL=0.0
      FLRMOL=0.0
      FLRMAL=0.0
      FLRMCR=0.0
      DELSL=DALPHA(K)*RHC(K)
      SL=DELSL/2.
      GO TO 3000
C
C * * * FOR K GREATER THAN 1 * * *
C
  902 IF(K.GT.KNH)GOTO907
C     TB1(K)=TB1(K-1)
C     WRITE(6,2634) TW1(K)
C     WRITE(6,2635) TB1(K)
C2634 FORMAT(5X,'TW1(K)= ',F10.0)
C2635 FORMAT(5X,'TB1(K)= ',F10.0)
```

```
C2838 FORMAT(5X,'GRAD= ',E12.5)
      FLRMAR=FLRMA/2.*(COS(ALPHN(K-1))-COS(ALPHN(K)))
      IF(FLRMAR.LT.0.0)FLRMAR=0.0
  907 SL=SL+DELSL/2.0
      IF(K.LE.KNH) DELSL=RHO(K)*DALPHA(K)
      IF(K.GT.KNH) DELSL=XL(K)
      SL=SL+DELSL/2.0
      IF(K.GT.KNH) GOTO 908
 3000 FLRMAR=FLRMAR+FLRMAL
      FLRMBV=FLRMAR+FLRMBL
      GOTO 909
  908 IF(K.EQ.(KNH+1))FLRMBV=FLRMBL+FLRMA/2.0+FLRMAL
      IF(K.GT.(KNH+1))FLRMBV=FLRMBV+FLRMCR*(1.0+GMXS)
  909 RHOB=RHO(P,BMW,TB1(K))
      IF(K.LE.KNH.AND.RHO(K).LE.DLZ(K)-DZCH)KCHR=1
      IF(K.GT.KNH.AND.DIA(K).LE.DLZ(K)-2.*DZCH)KCHR=1
      TREF=TREFCL
      IF(KCHR.EQ.1)TREF=TREFCH
      IF(KSEAM(K).EQ.2) GOTO 403
      IF(K.GT.KNH) GOTO 403

C * * * FOR THICK SEAM AND K LESS THAN KNH (IN HEM.) * * *

      ALT=RHO(K)*COS(ALPHA(K))
      RCONE=DIA(K)/2.0
      ACONE=PI*RCONE*SQRT(RCONE**2+ALT**2)
      VELB=FLRMBV/(RHOB*ACONE)
      IF(K.EQ.1) VELB=FLRMAR/(RHOB*ACONE)
      GOTO 407

C * * * FOR THIN SEAM AND STEP-CYLINDER REGION * * *

  403 VELB=FLRMBV/(RHOB*AS)
  407 TCIRC=TW1(K)
      IF(K.LE.KNH)TCIRC=TAIR
      TFILM=(TCIRC+TBKMN)/2.
      RA=RHO(P,BMW,TFILM)**2*GC/TFILM*ABS(TCIRC-TBKMN)*
     * HEIGHT**3*PR/VISCTY(TFILM)**2
      IF(RA.GT.1.0E9)GOTO 408
      VBLAV=0.431*(GC*ABS(TCIRC-TBKMN)*HEIGHT/TFILM/(0.952+PR))**0.5
      GOTO 409
  408 VBLAV=0.173*(GC*ABS(TCIRC-TBKMN)*HEIGHT/TFILM/(1.0+0.494*PR**0
     *.666))**0.5
  409 DCIRC=(DELSL*VBLAV)/(VELB*CHLNTH)
      IF(K.GT.KNH)GOTO106
      FN=1.0-EXP(-DCIRC/CIRCT1/2.)
      ALCNST=PI/2./2.
      WTHMS=1.-EXP(-ALPHA(K)/ALCNST)
      WTHMS=1.0
      FN=FN*WTHMS
```

```
      FLRMAS=FLRMAR*(1.-FN)
      FLRMAM=FLRMAR*FN
      FLRMBS=FLRMBL+FLRMAM
      FLRMDS=FLRMDL+WO2*FLRMAM
      GOTO905
  106 CIRC(K)=CIRC(K-1)+DCIRC
      IF(K.EQ.KNH+1) FLRMAC=FLRMA/2.0+FLRMAL
      IF(K.EQ.KNH+1) FN=0.
      IF(K.EQ.KNH+1) SFN=0.0
      WTEXMX=1.0
      FN=(EXP(-CIRC(K-1)/CIRCT1)-EXP(-CIRC(K)/CIRCT1))*WTEXMX
      SFN=SFN+FN
      FLRMAS=FLRMAC*(1-SFN)
      IF(FLRMAS.LT.0.) FLRMAS=0.
      FLRMAM=FLRMAC*FN
      FLRMBS=FLRMBL+FLRMAC*FN
      FLRMDS=FLRMDL+WO2*FLRMAC*FN
  905 CONTINUE
C     WRITE(6,7001)FLRMA,FLRMAL,FLRMAM,FLRMAR,FLRMAS,FLRMBS,FLRMBL,
C    1 FLRMDS,FLRMBV
C7001 FORMAT(5X,'FLRMA    FLRMAL    FLRMAM    FLRMAR    FLRMAS    FLRMBS
C    1    FLRMBL    FLRMDS    FLRMBV',//9F10.3,/)
C
C ***** HEAT AND MASS TRANSFER *****
C
      ITER=0
      IF(K.GT.KNH)GOTO914
      ZB=PI*DIA(K)/SIN(ALPHA(K))
      IF(KSEAM(K).EQ.2)ZB=2.0*SMTK/SIN(ALPHA(K))
      GOTO912
  914 ZB=PI*DIA(K)
      IF(KSEAM(K).EQ.2) ZB=(AW*WFRCT)/XL(K)
  912 CONTINUE
      B1=2.33*YC*CPCO+(0.167*YC+YH-0.125*YOX)*FWG*CPH2
     *+(FWG*1.125*YOX+YMOIST+GMXS-GMR+FOX*9.0*YH)*CPH2O+
     *  FOX*2*YS*CPSO2
      B2=YASH*CPASH+FOX*YS*CPS
      IF(KCHR.EQ.1)B2=YASH*CPASH*RCHO2/RCO2
      B3=CPO2/RCO2
      A2=(B1+B2-B3)*RCO2
      IF(KCHR.EQ.1)A2=RCHO2*((2.333*COCO2*CPCO+3.667*CPCO2)/(1.+COCO2)
     1  +YASH*CPASH/YFC)-CPO2
      QOX=FOX*(YC*HCCO+YH*HCH2O+YS*HCSO2+YASH*HSLASH)
      QWG=FWG*(YC*HRWG+YS*HSLS+YASH*HSLASH+0.125*YOX*HCH2O)
      QFG=(GMXS+YMOIST)*HFGH2O
      A3=RCO2*(QOX+QWG+QFG)
C THE KCHR=1 RELATIONS FOR A2&A3 HAVE NO WG REACTION VIA EXP DATA.
      IF(KCHR.EQ.1)A3=RCHO2*(FOXCH*(COCO2*HCCO+HCCO2)/(1.+COCO2)
     1  +YASH*HSLASH/YFC)
      IF(KSEAM(K).EQ.2)TWB(K)=(TW1(K)+TREFCL)/2.
      IF(KSEAM(K).EQ.2.AND.NTHICK.EQ.1)TWB(K)=(TBKMN+TREFCL)/2.
```

```
C
C NI LOOP    NI LOOP    NI LOOP    NI LOOP
C
      N4=80
  904 CONTINUE
C IF TBI(K) OR TBKMN EXCEED TREFCL+N4*DELT-DELT,INC. N4 VALUE ACCORDINGLY
C A FLAG INDICATING THIS IS WHEN NI REACHES N4 OR TW REPEATS ITS VALUE
      DO 911 NI=NII,N4
      TI(NI)=TREFCL+DELT*NI-DELT
      TW1(K)=TI(NI)
      IF(NI.GT.15)NII=NI-15
      IF(NI.EQ.80)GO TO 9511
      TCIRC=TW1(K)
      IF(K.LE.KNH)TCIRC=TAIR
      CALL HMTR(VEL2,P,BMW,RR,DO,CPAIR,SL,HEIGHT,TBKMN,TCIRC,RNU(K),RE,
     *RA,HMF,HMN,HC,HM,I,K,ITER)
      ITER=ITER+1
C
C * * * RESTRICTED FLOW CALCULATION * * *
C
      TERM=HM*ZB*XL(K)*RHOB/FLRMBS
      IF(TERM.GT.150) GO TO 511
      FLRMOL=FLRMOS*EXP(-TERM)
      GO TO 512
  511 FLRMOL=0.0
  512 FLRMOY=FLRMOS-FLRMOL
      FLRMCR=RCO2*FLRMOY
      IF(KCHR.EQ.1)FLRMCR=RCH02*FLRMOY
C
C***** THE FOLLOWING EQUATIONS CALCULATE THE TEMPERATURE OF THE WALL
C       AND THE TEMPERATURE OF THE BLAST AT EACH SECTION USING THE
C       CONVECTIVE AND RADIATIVE ENERGY BALANCES. *****
C
      IF(NTHICK.EQ.2)GOTO 514
      QRADTK = AW*WFRCT*SIGM*(TW1(K)**4-TBKMN**4)
      QRADBTK=AW*(1-WFRCT)*SIGM*(TWB(K)**4-TBKMN**4)
      QRADB=QRADBTK
      QRAD=QRADTK
      GOTO 516
  514 CALL RAD(TW1,TB1,TWB,DIA,XL,KSEAM,K,SMTK,KMAX,RHC1,HR,QRAD,HRB,
     * QRADB,ITER,I)
      QRADB=QRADB/2.
      QRAD=QRAD-QRADB
      QRADTK=0.0
      QRADBTK=0.0
  516 A1=HC*AW*WFRCT
      A4=HC*AW*(1.0-WFRCT)
      QCONV=HC*AW*WFRCT*(TW1(K)-TBKMN)
      QCONVB=A4*(TWB(K)-TBKMN)
      TWNI=TBKMN
      FLRMBX=FLRMBL+FLRMAM+FLRMCR*(1.+GMXS)
```

```
C      WRITE(6,7002)B1,B2,B3,A1,A2,A3,FLRM3X,FLRMOY,ZB
C7002 FORMAT(8X,'B1',8X,'B2',8X,'B3',8X,'A1',8X,'A2',8X,'A3',4X,'FLRMBX'
C     1 ,4X,'FLRMOY',8X,'ZB',//,9F10.3,/)
C      WRITE(6,7003) I,K,KSEAM(K),AW,WFRCT,WOX,FN,SFN,XL(K),RHOB
C7003 FORMAT(5X,'    I   K KSEAM',8X,'AW',5X,'WFRCT',7X,'WOX',6X,'FN',
C     1 7X,'SFN',5X,'XL(K)',6X,'RHOB',//,5X,3I5,7F10.3,/)
      C11=-A1-FLRMOY*(A2-B2*RCO2)
C B2*RCO2 FOR KCHR=1 IS CORRECTED ABOVE
      C12=A1+A4+2*FLRMBX*CPGAS
      C21=-A1-FLRMOY*A2
      C22=A1
      DFRST=(FLRMBL+FLRMBX)*CPGAS*TB1(K)+FLRMAM*CPAIR*TAIR
     1  +GRADTK+GRADBTK+A4*TWB(K)
      DSCND=GRAD-A2*FLRMOY*TREF+A3*FLRMOY
      TW1(K)=(DFRST*C22-C12*DSCND)/(C11*C22-C12*C21)
      IF(TW1(K).GT.1.0E4)TW1(K)=0.99E4
      IF(TW1(K).LT.TREFCL)TW1(K)=TREFCL-1.
      TBKMN1=TBKMN
      TBKMN=(C11*DSCND-DFRST*C21)/(C11*C22-C12*C21)
      IF(TBKMN.LT.TBKMN1-500.)TBKMN=TBKMN1-500.
      IF(TBKMN.GT.1.0E4)TBKMN=0.95E4
      IF(TBKMN.LT.TREFCL)TBKMN=TREFCL-1.
C      IF(I.EQ.21)
C     *WRITE(6,7004)I,K,NII,NI,KSEAM(K),KCHR,TI(NI),TBKMN,TB1(K+1),TW1(K)
C     *,TWB(K),QCONV,QCONV3,QRAD,QRADB,GRADTK,GRADBTK,A1,A4,A2,A3,TWNI
      TO(NI)=TW1(K)
      FOFTI(NI)=TO(NI)-TI(NI)
      IF(NI.EQ.NII) GOTO 911
      IF((FOFTI(NI-1)*FOFTI(NI)).LT.0.) GOTO 916
      GOTO 911
  916 TI1=TI(NI-1)
      TO1=TO(NI-1)
      TI2=TI(NI)
      TO2=TO(NI)
      GOTO 910
  911 CONTINUE
      GO TO 910
 9511 NII=1
      N4=N4-1
      GO TO 904
  910 TW1(K)=(TI1*TO2-TO1*TI2)/(TO2-TI2-TO1+TI1)
      TBKMN=TBKMN1+(TW1(K)-TI1)/(TI2-TI1)*(TBKMN-TBKMN1)
      TB1(K+1)=2*TBKMN-TB1(K)
      IF(TB1(K+1).LT.TREFCL) TB1(K+1)=TREFCL-1.
      IF(TB1(K+1).LE.TREFCL+1) TBKMN=(TB1(K)+TB1(K+1))/2
C      TWB(K)=TW1(K)
C      IF(KSEAM.EQ.1)GOTO 518
C      QCONDB=-QCONVB-QRADB
C      TWB(K)=TREF+ERFC(XXXXX), ETC.
  518 FLRMAL=FLRMAS
C      IF(I.LT.13.AND.K.LT.15)GO TO 7901
```

```
C      WRITE(6,7004)I,K,NII,NI,KSEAM(K),KCHR,TB1(K),TBKMN,TB1(K+1),TW1(K)
C     *,TWB(K),QCONV,QCONVB,QRAD,QRADB,QRADTK,QRADBTK,A1,A4,A2,A3,TWNI
 7004 FORMAT(1X,4I4,2I2,11F7.0,3F7.2,2F7.0)
C
C * * * CALCULATE NEW CAVITY SHAPE * * *
C
 7801 DRHC=RCO2*FLRMOY*DELTAT*60./(RHOC*AW*WFRCT)
      DDLZ=DRHC
      IF(K.GT.KNH) GO TO 501
C
C * * * FOR K LESS THAN KNH * * *
      IF(KCHR.EQ.2)GOTO 503
      DRHC=FLRMCR*DELTAT*60/(YFC*RHOC*AW*WFRCT)
      DDLZ=0.0
  503 RHC(K)=RHC(K)+DRHC
      DIA(K)=2.*RHC(K)*SIN(ALPHA(K))
      IF(K.EQ.1) XMIN=-RHC(K)
      TL(K)=-RHC(K)*COS(ALPHA(K))
      XL(K)=2.*RHC(K)*SIN(DALPHA(K)/2.)*SIN(ALPHA(K))
      GO TO 502
C
C * * * FOR K GREATER THAN KNH * * *
  501 IF(KCHR.EQ.2)GOTO 504
      DRHC=FLRMCR*DELTAT*60./(YFC*RHOC*AW*WFRCT)
      DDLZ=0.0
  504 DIA(K)=DIA(K)+2.*DRHC
  502 FLRMBL=FLRMBS+FLRMCR*(1.0+GMXS)
      FLRMBT=FLRMBV+FLRMCR*(1.0+GMXS)
      WOX=FLRMOL/FLRMBL
C     DLZ(K)=DLZ(K)+DDLZ
      IF(KCHR.EQ.2.AND.K.LE.KNH)DLZ(K)=RHC(K)+DZCH
      IF(KCHR.EQ.2.AND.K.GT.KNH)DLZ(K)=DIA(K)+DZCH
      IF(KCHR.EQ.2)VMC=VMC+RCO2*YVM*FLRMOY*DELTAT*50./2000.*
     *  (1.+RCHNR/(1.-RCHNR))
C     IF(KCHR.EQ.1)VMC=VMC
      IF(KCHR.EQ.1)CHC=CHC+RCHO2*FLRMOY*DELTAT*60./2000.
      IF(KCHR.EQ.2)CHC=CHC+FLRMCR*YFC*DELTAT*60./2000.
      CC=VMC+CHC
      CAFF=VMC/YVM
      GOXW=FLRMOY/AW/WFRCT
      WOXT=(FLRMOL+FLRMAL*WO2)/FLRMBV
      IF(ABS(DAY+0.02-NDAY).GE.1.0) GOTO 84
      IF(DAY.GE.DAYMAX-.01)GOTO 84
      GO TO 7
   84 IF(K.LE.KNH) TBK=TBKMN
      IF(K.GT.KNH) TBK=TB1(K+1)
      WRITE(6,7510) DAYJ2
 7510 FORMAT(6X,F5.1)
      WRITE(6,90)I,K,FN,TL(K),DIA(K),FLRMBL,FLRMOY,FLRMOL,CHC,WOX,
     *RE,RA,HMN,HM,FLRMBT,GOXW,KSEAM(K),KCHR,SCFM,TW1(K),TBK    ,DCIRC
   90 FORMAT(1X,I3,I3,1X,F6.4,1X,F6.2,1X,F5.2,1X,F6.2,2F6.2,F6.0,
     *F6.3,2E10.3,F5.2,F6.2,F6.1,F7.4,I2,1X,I3,1X,F5.0,2F6.0,1X,F6.2)
```

```
C      WRITE(6,300)TW1(K),TB1(K),TL(K)
C  300 FORMAT(' ','TW1(K)=',F6.0,2X,'TB1(K)=',F6.0,2X,'TL(K)=',F6.2)
    7  CONTINUE
C
C      SMOOTHS A SET OF DATA POINTS BY AVERAGING ADACENT CHANNELS.
       NPTS=KMAX
C      CALL SMOOTH(TW1,NPTS)
C      CALL SMOOTH(TB1,NPTS)
C
C ***** LINK ZONE BURN WITH REMAINING OXYGEN *****
C
   61  IF(I.EQ.2) DIA(KD)=2.*RHC1
C        OXYGEN REMAINING BURNS CAVITY TO MEAN DIAMETER
C        OF DIA(KD,I-1) AND DIA(KD-1,I)
       DIA(KD)=(DIA(KD)+DIA(KD-1))/2.
       TLAV=TL(KD-1)+XL(KD-1)/2.
       IF(KD.EQ.KNH+2) TLAV=TL(KNH+1)+0.1
       NTERMS=4
       CALL INTERP(TLX,DIAX,NDPTS,NTERMS,TLAV,DLZ(KD))
       IF(DLZ(KD)-1.128*SMTK)100,101,101
C *** CALCULATE AREA OF LINK ZONE USING RECTANGULAR GEOMETRY ***
  101  ARLZ=(DLZ(KD)*SMTK)*POR
       GOTO102
C *** CALCULATE AREA OF LINK ZONE USING CIRCULAR GEOMETRY ***
  100  ARLZ=(PI*DLZ(KD)**2/4.0)*POR
  102  IF(DIA(KD)-1.128*SMTK)103,104,104
C *** THIN SEAM ***
  104  KSEAM(KD)=2
       ACR=(DIA(KD)*SMTK)*(1.0-POR)
       IF(DIA(KD).GT.DLZ(KD))ACR=(SMTK*DIA(KD))-ARLZ
       GOTO105
C *** THICK SEAM ***
  103  KSEAM(KD)=1
       ACR=((PI*DIA(KD)**2)/4.0)*(1.0-POR)
       IF(DIA(KD).GT.DLZ(KD))ACR=(PI*DIA(KD)**2)/4.0-ARLZ
  105  FLRMOY=FLRMOL+WO2*FLRMAL
       KCHR=2
       IF(DIA(KD).LT.DLZ(KD)-2.*DZCH)KCHR=1
       XL(KD)=(RCO2*FLRMOY*DELTAT*60.0)/(RHOC*ACR)
       IF(KCHR.EQ.1)XL(KD)=RCHO2*XL(KD)/RCO2
C      IF(XL(KD).LT.0.5) DELTAT=DELTAT*2.0
C      IF(XL(KD).GT.1.5) DELTAT=DELTAT/2.0
       FLRMCR=FLRMOY*RCO2
       IF(KCHR.EQ.1)FLRMCR=FLRMOY*RCHO2
       FLRMBL=FLRMBL+FLRMAL+FLRMCR*(1.+GMXS)
       FLRMBT=FLRMBV+FLRMCR*(1.0+GMXS)
       TB1(KD+1)=(-FLRMOY*A3+(FLRMBT-FLRMCR*(1.+GMXS))
      1  *CPGAS*TB1(KD)+FLRMCR*(1.+GMXS)*CPCOAL*TLZ1)/(FLRMBT*CPGAS)
       TLZ1=TB1(KD+1)
       TL(KD)=TL(KD-1)+XL(KD)
       DIA(KD+1)=DIA(KD)
```

```
      IF(DIA(KD).GT.DLZ(KD))DIA(KD+1)=DLZ(KD)
      IF(KCHR.EQ.2)VMC=VMC+YVM*RHOC*XL(KD)*ACR/2000.*
     *  (1.+RCHNR/(1.-RCHNR))
C     IF(KCHR.EQ.1)VMC=VMC
      IF(KCHR.EQ.1)CHC=CHC+RCHO2*FLRMOY*DELTAT*60./2000.
      IF(KCHR.EQ.2)CHC=CHC+FLRMCR*YFC*DELTAT*60./2000.
      CC=VMC+CHC
      CAFF=VMC/YVM
      WRITE(6,540)VMC,CHC,CC,CAFF
C
C ENHANCE LINK BY DEVOLATLIZING VOL MAT WITH PC ENTHALPY
      IF(TL(KD).GE.TLMAX)GOTO 4114
      CALL GLINKE(FLRMBT,P,BMW,PR,YVM,YMOIST,TL(KD),TB1(KD-1),TREFCL,
     1  TVOL,SMTK,KD,VMC,RHOC,I,DELTAT,CPGAS,DNC,GMXS)
 4114 CONTINUE
C THE FOLLOWING SMOOTHS BY AVERAGING K-1,2K,& K+1 VALUES.
      NPTS=KMAX
      CALL SMOOTH(DIA,NPTS)
      CALL SMOOTH(RHC,NPTS)
C     IF(ABS(DAY+0.02-NDAY).GE.1.0) GOTO 49
C     IF(DAY.GE.DAYMAX-.01)GOTO 49
C     GOTO 25
      IF(ABS(DAY-.5).LE.0.01)GO TO 5520
      IF(ABS(DAY-1.).LE.0.01)GO TO 5520
      IF(ABS(DAY-11.75).LE.0.01)GO TO 5520
5521  IF(DAY.GT.DAYMAX+.01)GO TO 49
      SSS=0.
      DO 5519 JJ7=2,10,2
      SSS=SSS+2.
      IF(ABS(DAY-SSS).LE.0.01) GO TO 5520
 5519 CONTINUE
      GO TO 25
 5520 CALL PLTPLN(N,KDIR)
      CALL PLT2DL(DIAX)
      CALL PLT2DL(DIAL)
      CALL PLT2D(SCFM,KD)
      CALL PLTDLZ(KNH,KD,DLZ)
      CALL PLOT(10.,0.,-3)
      GOTO 49
   49 WRITE(6,47)I,KD,XMIN,TL(KD),DIA(KD),FLRMBL,FLRMOY,
     *FLRMOL,CHC,WOX,FLRMBT,KSEAM(KD),KCHR,TW1(KD),TB1(KD+1)
   47 FORMAT(1X,I3,I3,1X,F6.2,1X,F6.2,1X,F5.2,1X,F6.2,2F6.2,
     *F6.0,F6.3,31X,F6.1,7X,I2,I3,1X,6X,2F6.0)
      WRITE(6,540)VMC,CHC,CC,CAFF
      WRITE(6,1321) TLAV,XL(KD),TLX(KD),DIAX(KD),DLZ(KD)
1321  FORMAT(5(3X,F8.2))
      IF(ABS(DAY-DAYMAX).LE.0.02) GO TO 130
   25 KD=KD+1
      KMAX=KMAX+1
   22 CONTINUE
  130 CONTINUE
```

```
      CALL PLOT(0.0,0.0,999)
      STOP
      END
C      SUBPROGRAMS
C      SUBPROGRAMS
       FUNCTION RHO(P,WM,T)
       RHO=P*144.*WM/(1545.*T)
       RETURN
       END
      FUNCTION DIX(DO,P,T)
C     UNITS OF DIFFUSION COEFFICIENT ARE SQ FT/MIN
      DIX=(DO/P*14.7)*(T/(1.8*300.0))**1.5
      RETURN
      END
      FUNCTION VISCTY(TFILM)
C     UNITS OF DYNAMIC VISCOSITY ARE LBM/FT-MIN
      VISCTY=7.300E-07*TFILM**0.5/(1+198.07/TFILM)*60.
      RETURN
      END
      FUNCTION THCDTY(TFILM)
      S=205.2
      TREF=1960.0
      REFK=0.04
      THCDTY=REFK*(TFILM/TREF)**1.5*(TREF+S)/(TFILM+S)/60.0
      RETURN
      END
      SUBROUTINE HMTR(V,P,WM,PR,DO,CPAIR,X,D,TB,TW,RNU,RE,RA,
     *HMF,HMN,HC,HM,I,K,ITER)
      TFILM=(TW+TB)/2
      GC=32.2*3600.
      SCH=0.95
      THCOND=THCDTY(TFILM)
      RHOB=RHO(P,WM,TFILM)
      VISB= VISCTY(TFILM)
      DOX=DIX(DO,P,TFILM)
      RE=RHOB*V*X/VISB
C     FORCED CONVECTION IN INJECTION REGION
  670 IF (RE.LE.5.0E+05) GO TO 3
      ANUP=0.0287*(RE**0.8)*(PR**0.333)
      GO TO 5
    3 ANUP=0.332*(RE**0.5)*(PR**0.333)
    5 ANUF=ANUP*RNU
      HMF=ANUF*(DOX/X)*(SCH/PR)**0.333
C     NATURAL CONVECTION IN INJECTION REGION
      RA=((RHOB**2)*GC/TFILM)*ABS(TW-TB)*(D**3*PR/VISB**2)
      IF (RA.LE.1.0E9) GO TO 10
      ANUN=0.10*RA**0.350
C     ANUN=(0.825+0.387*RA**0.1667/(1.+(0.492/PR)**0.5625)**0.2963)**2
      GO TO 6
   10 ANUN=0.59*RA**0.25
    6 HMN=ANUN*(DOX/D)*(SCH/PR)**0.333
      HM=(HMF**2+HMN**2)**0.5
```

```
      HC=HM*THCOND/DOX*(PR/SCH)**0.333
C     WRITE(6,25) V,DO,X,D,RE,RA,HMF,HM,HC,ITER,I,K,TW,TB
   25 FORMAT(9X,'V',7X,'DOX',8X,'X',7X,'DNC',8X,'RE',8X,'RA',7X,'HMF',
     * 8X,'HM',6X,'HC  ITER  I  K',8X,'TW',6X,'TBIN',//,
     * 9E10.3,1X,3I3,2F10.0,/)
      RETURN
      END
          SUBROUTINE RAD (TW1,TB1,TWB,DIA,XL,KSEAM,KK,SMTK,N,RHC1,HR,
     *QRAD,HRB,QRADB,ITER,ITIME)
      DIMENSION TW1(125),TWB(125),TB1(125),DIA(125),KSEAM(125),D(125),
     *X(125),XL(125),F(125,125),R(125),S(125)
C
C ***** N IS EQUAL TO KMAX *****
C
      SIGM=2.85 E-11
      PI=3.1415927
C
C ***** CALCULATE XL(WIDTH OF ELEMENT), X(DISTANCE TO CENTER OF ELEMENT,
C       AND D(DIAMETER). *****
C
      DO 5 J=1,N
C     TWB(J)=1000. TWB IS SET FROM MAIN PROGRAM
      D(J)=DIA(J)
      IF(KSEAM(J).EQ.2) D(J)=2./PI*(DIA(J)+SMTK)
    4 X(1)=0.
      IF(J.GT.1) X(J)=X(J-1)+.5*(XL(J-1)+XL(J))
    5 CONTINUE
C
C ***** S=SINE(ETA), R=COSINE(ETA), ETA=ANGLE OF ELEMENT *****
C
      S(1)=(D(1)-D(2))/SQRT((D(2)-D(1))**2+4.*(X(2)-X(1))**2)
      S(N)=(D(N)-2.*RHC1)/SQRT((2.*RHC1-D(N))**2+4.*(X(N)-X(N-1))**2)
      DO 10 I=1,N
      F(I,I)=1.-SQRT(1.+(XL(I)/D(I))**2)+XL(I)/D(I)
      IF(I.EQ.1.OR.I.EQ.N) GOTO 9
      S(I)=(D(I-1)-D(I+1))/SQRT((D(I+1)-D(I-1))**2
     *+4.*(X(I+1)-X(I-1))**2)
    9 R(I)=SQRT(ABS(1.-S(I)*S(I)))
   10 CONTINUE
      IF(ITER .GT. 1) GO TO 38
      NN=N-1
      DO 20 I=1,NN
      IF(I.GT.KK) GO TO 21
      II=I+1
      DO 30 J=II,N
      IF(I.LT.KK.AND.J.NE.KK) GO TO 30
      FL1=2.*(X(J)-X(I))/D(I)
      R1=D(J)/D(I)
      A=R1*R1*R(J)*(R(I)-FL1*S(I))+R1*FL1*S(J)*(R(I)-FL1*S(I))
      B=(-R1)*R1*R(I)*(R1*R(J)+FL1*S(J))+R1*R(J)*(FL1*S(I)-R(I))
      C=R1*R1*R(J)*R(I)
```

```
      D1=R1*R1+FL1*FL1+1.
      E=(-2.)*R1
      D2=D1*D1-E*E
      E2=SQRT(ABS(D2))
      IF(J.EQ.I+1) GOTO 34
      JJ=J-1
C
C ***** BLOCKING BY INTERMEDIATE SEGMENT *****
C
      S0=0.
      DO 25 K=II,JJ
      S1=.5*(D(I)-D(K))*(X(J)-X(I))/(X(K)-X(I))
      IF(S1.GE.(D(I)+D(J))/2.) GOTO 50
      Z1=.5*(X(J)-X(I))/(X(K)-X(I))*(D(I)+D(K))
      IF(Z1.LT..5*(D(I)+D(J))) GOTO 50
      IF(K.EQ.I+1) GOTO 26
      IF(S1.LT.S0) GOTO 25
   26 S0=S1
      L3=K
   25 CONTINUE
      IF(S0-(D(I)-D(J))/2.) 34,34,35
   35 T1=ACOS(((D(I)*(X(J)-X(L3)))**2+(D(J)*(X(L3)-X(I)))**2-(D(L3)
     **(X(J)-X(I)))**2)/(2.*D(I)*D(J)*(X(J)-X(L3))*(X(L3)-X(I))))
      GO TO 27
   34 T1=PI
C
C ***** BLOCKING BY HORIZON *****
C
   27 S2=(X(J)-X(I))*S(I)/R(I)
      IF(S2.GE..5*(D(I)+D(J))) GOTO 50
      IF(S2.LE..5*(D(I)-D(J))) GOTO 29
      T2=ACOS((2.*S2-D(I))/D(J))
      GOTO 31
   50 F(I,J)=0.
      GOTO 37
   29 T2=PI
C
C ***** BLOCKING DUE TO ORIENTATION OF A(J) *****
C
   31 S3=(2.*(X(J)-X(I))*S(J)/R(J)+D(J))/D(I)
      IF(.5*(D(I)+D(J))/(X(J)-X(I)).LE.(-S(J)/R(J))) GOTO 50
      IF(ABS(S3).GE.1.) T3=PI
      IF(ABS(S3).LT.1.) T3=PI/2.+ASIN(S3)
      T0=AMIN1(T1,T2,T3)
      IF(T0.NE.PI) GOTO33
      F(I,J)=4.*XL(J)*((D1*(A-C*(D1/E)**2)-E*B+2.*C*D1)/(D2*E2)
     **+C/(E*E))/(D(I)*R(J))
      GOTO 37
   33 E1=D1+E*COS(PI-T0)
      V1=ATAN((D1-E)*TAN((PI-T0)/2.)/E2)
      G1=C*T0/(E*E)
```

```
      G2=D1*PI/(D2*E2)-E*SIN(PI-TO)/(-D2*E1)-2.*D1*V1/(D2*E2)
      G3=(-D1)*SIN(PI-TO)/(D2*E1)+2.*E*V1/(D2*E2)-E*PI/(E2*D2)
   36 F(I,J)=4.*XL(J)*(G1+G2*(A-C*D1*D1/(E*E))+G3*(B-2.*C*D1/E))/(PI*
     *R(J)*D(I))
   37 F(J,I)=F(I,J)*D(I)/D(J)*XL(I)/XL(J)*R(J)/R(I)
   30 CONTINUE
   20 CONTINUE
   21 CONTINUE
C     IF (ITIME.NE.14) GO TO 38
C     IF (KK.LT.7.OR.KK.GT.9) GO TO 38
C     DO 40 I=1,N
   40 CONTINUE
   38 QRAD=0.
      QRADB=0.
      IF(KSEAM(KK).EQ.1) AK=PI/R(KK)*D(KK)*XL(KK)
      IF(KSEAM(KK).EQ.2) AK=2.*SMTK*XL(KK)
      DO 70 J=1,N
      IF (KK.EQ.J) GO TO 70
      IF(KSEAM(KK).EQ.2) GO TO 80
      ATK=AK*TW1(KK)**4
      IF(KSEAM(KK).EQ.1.AND.KSEAM(J).EQ.2) ATJ=2.*D(J)*XL(J)*TWB(J)**4
     *+2.*SMTK*XL(J)*TW1(J)**4
      IF(KSEAM(KK).EQ.1.AND.KSEAM(J).EQ.1)ATJ=PI/R(J)*D(J)*XL(J)*TW1(J)
     ***4
      QRAD=QRAD+SIGM*(F(KK,J)*AK*TW1(KK)**4-F(J,KK)*ATJ)
C     IF (ITER.GT.0.OR.ITIME.NE.14) GO TO 70
C     IF ( KK.LT.7.OR.KK.GT.9) GO TO 70
      GO TO 70
   80 IF (KSEAM(J).EQ.2) GO TO 82
      ATJ=PI/R(J)*D(J)*XL(J)*SMTK/(SMTK+D(KK))*TW1(J)**4
      ATK=2.*SMTK*XL(KK)*TW1(KK)**4
      ATJB=D(KK)/(SMTK+D(KK))*PI/R(J)*D(J)*XL(J)*TW1(J)**4
      ATKB=2.*D(KK)*XL(KK)*TWB(KK)**4
   82 ATJ=SMTK/(SMTK+D(KK))*2.*XL(J)*(SMTK*TW1(J)**4+D(J)*TWB(J)**4)
      ATK=2.*XL(KK)*(SMTK*TW1(KK)**4+D(KK)*TWB(KK)**4)
      ATJB=D(KK)/(D(KK)+SMTK)*2.*XL(J)*(SMTK*TW1(J)**4+D(J)*TWB(J)**4)
      ATKB=2.*D(KK)*XL(KK)*TWB(KK)**4
   84 QRAD=QRAD+SIGM*(F(KK,J)*ATK-F(J,KK)*ATJ)
      QRADB=QRADB+SIGM*(F(KK,J)*ATKB-F(J,KK)*ATJB)
      IF (ITER.GT.0.OR.ITIME.NE.14) GO TO 70
      IF ( KK.LT.7.OR.KK.GT.9) GO TO 70
   70 CONTINUE
      QRAD=QRAD+QRADB/2.
      IF(KK.EQ.1) TBKMN=905
      IF(KK.EQ.1) GO TO 68
      TBKMN=TB1(KK)
   68 IF (ABS(TW1(KK)-TBKMN).LE..001) TBKMN=TBKMN-20.
      HRB=QRADB/(2*D(KK)*XL(KK)*(TW1(KK)-TBKMN))
   69 TDIFF=ABS(TW1(KK)-TBKMN)
      IF(TDIFF .LT. 10) GO TO 55
      GO TO 56
```

```
C  55 IF(TW1(KK) .GT. TBKMN) TW1(KK)=TW1(KK)+10.0
C     IF(TW1(KK) .LT. TBKMN) TBKMN=TBKMN+10.0
C  56 CONTINUE
C  60 HR=QRAD/(AK*(TW1(KK)-TBKMN))
      RETURN
      END
      SUBROUTINE INTERP (X,Y,NPTS,NTERMS,XIN,YOUT)
      DOUBLE PRECISION DELTAX,DELTA,A,PROD,SUM
      DIMENSION X(125),Y(125),DELTA(10),A(10)
C
C          SEARCH FOR APPROPRIATE VALUE OF X
C
   11 DO 19 I=1,NPTS
      IF(XIN-X(I))13,17,19
   13 I1=I-NTERMS/2
      IF(I1)15,15,21
   15 I1=1
      GOTO21
   17 YOUT=Y(I)
   18 GOTO61
   19 CONTINUE
      I1=NPTS-NTERMS+1
   21 I2=I1+NTERMS-1
      IF(NPTS-I2)23,31,31
   23 I2=NPTS
      I1=I2-NTERMS+1
   25 IF(I1)26,26,31
   26 I1=1
   27 NTERMS=I2-I1+1
C
C          EVALUATE DEVIATIONS DELTA
C
   31 DENOM=X(I1+1)-X(I1)
      DELTAX=(XIN-X(I1))/DENOM
      DO 35 I=1,NTERMS
      IX=I1+I-1
   35 DELTA(I)=(X(IX)-X(I1))/DENOM
C
C          ACCUMULATE COEFFICIENTS A
C
   40 A(1)=Y(I1)
   41 DO 50 K=2,NTERMS
      PROD=1.0
      SUM=0.0
      IMAX=K-1
      IXMAX=I1+IMAX
      DO 49 I=1,IMAX
      J=K-I
      PROD=PROD*(DELTA(K)-DELTA(J))
   49 SUM=SUM-A(J)/PROD
   50 A(K)=SUM+Y(IXMAX)/PROD
```

```
C
C          ACCUMULATE SUM OF EXPANSION
C
   51 SUM=A(1)
      DO 57 J=2,NTERMS
      PROD=1.0
      IMAX=J-1
      DO 56 I=1,IMAX
   56 PROD=PROD*(DELTAX-DELTA(I))
   57 SUM=SUM+A(J)*PROD
   60 YOUT=SUM
   61 RETURN
      END
      SUBROUTINE PLTPLN(N,KDIR)
C     CALL SYMBOL(4.3,7.15,.300,'PRICETOWN I',0.,11)
      CALL SYMBOL(2.3,5.4,.140,'W',0.,1 )
      CALL SYMBOL(2.2,5.1,.140,'(FT)',0.,4 )
C     CALL SYMBOL(4.8,6.7,.200,'PHASE:',0.,6)
      CALL SYMBOL(7.5,6.7,.200,'DAY=',0.,4)
      CALL SYMBOL(3.8,6.3,.100,'P/I-1',0.,5)
      CALL SYMBOL(6.8,6.3,.100,'P/I-2',0.,5)
      CALL SYMBOL(9.05,6.3,.100,'P/I-3',0.,5)
      CALL SYMBOL(5.1,6.7,.200,'FG ',0.,3)
      CALL SYMBOL(2.0,4.0,.100,'SEAM',0.,4)
C     IF(N.EQ.0) CALL SYMBOL(5.4,6.7,.200,'RCL',0.,3)
C     IF(N.GT.0) CALL SYMBOL(5.4,6.7,.200,'CLE',0.,3)
C     IF((N.EQ.48).AND.(KDIR.EQ.23)) CALL SYMBOL(5.4,6.7,.200,'CLE',0.,3)
C     IF((N.GT.48).AND.(KDIR.EQ.12)) CALL SYMBOL(5.4,6.7,.200,'RCL',0.,3)
C
      CALL SYMBOL(4.51,4.00,.100,'+ M1',0.,4)
      CALL SYMBOL(5.23,3.38,.100,'+ M2',0.,4)
      CALL SYMBOL(5.78,4.33,.100,'+ M3',0.,4)
      CALL SYMBOL(7.40,3.86,.100,'+ M4',0.,4)
      CALL SYMBOL(3.65,4.20,.100,'C1 +',0.,4)
      CALL SYMBOL(5.08,4.11,.100,'C3 +',0.,4)
      CALL SYMBOL(5.78,3.70,.100,'C4 +',0.,4)
      CALL SYMBOL(3.73,3.93,.140,'+',0.,1)
      CALL SYMBOL(6.73,3.93,.140,'+',0.,1)
      CALL SYMBOL(8.98,3.93,.140,'+',0.,1)


      CALL WAXHT(0.1,0.1)
      CALL AXIS(2.9,2.0,' ',0 ,4.0,90.,-40.,20.,-5.)
      CALL AXIS(6.7,2.0,' ',0,4.0,90.,-40.,20.,-5.)
      CALL AXIS(8.95,2.0,' ',0,4.0,90.,-40.,20.,-5.)
      CALL AXIS(2.8,1.5,'L(FT)',-5,7.0,0.,-20.,20.,10.)
      CALL PLOT(2.2,4.05,3)
      CALL AROHD(2.2,4.175,2.2,4.775,0.3,0.1,11)
      CALL PLOT(2.2,3.975,3)
      CALL AROHD(2.2,3.825,2.2,4.425,0.3,0.1,11)
      CALL PLOT(1.9,3.825,3)
      CALL DASHPT(2.5,3.825,0.05)
```

```
      CALL PLOT(1.9,4.175,3)
      CALL DASHPT(2.5,4.175,0.05)
      RETURN
      END
      SUBROUTINE PLT2D(SCFM,KD)
      COMMON N,TL(125),DIA(125),DIP(125),DIN(125),TLP(125),DAY,KDIR
     *,ALPHA(125),DALPHA(125),XL(125),RHO(125),KSEAM(125),ALPHN(125)
     *,RNU(125),TLX(122),DIAX(122),KSMLZ(122),NDAY,DAYMAX,DIAL(122)
      K2=89
      K3=85
C
      K1=1
C     IF(DAY.LE.30.0)K1=77
      DO 33 L =K1,KD
      TLP(L)=TL(L)/20.0
      DIN(L)=DIA(L)/20.0/2.
      DIP(L)=-DIN(L)
   33 CONTINUE
C
      CALL NUMBER(8.4,6.,.200,DAY,0.,1)
C
      CALL PLOT(3.8,4.,-3)
      CALL PLOT(TLP(K1),DIN(K1),3)
      DO 30 L=K1,KD
C     IF((L.GT.K2).AND.(L.LT.K3).AND.(DAY.GT.30.0))GOTO30
      CALL PLOT(TLP(L),DIN(L),2)
   30 CONTINUE
      CALL PLOT(TLP(K1),DIN(K1),3)
      DO 31 L=K1,KD
C     IF((L.GT.K2).AND.(L.LT.K3).AND.(DAY.GT.30.0))GOTO31
      CALL PLOT(TLP(L),DIP(L),2)
   31 CONTINUE
      CALL PLOT(TLP(KD),DIN(KD),2)
C     CALL PLOT(TLP(KI),DIP(KI),2)
      CALL PLOT(-3.8,-4.,-3)
      IF(KDIR.EQ.123) GOTO 70
      IF((KDIR.EQ.11).OR.(KDIR.EQ.13)) GOTO 10
      IF((KDIR.EQ.21).OR.(KDIR.EQ.23)) GOTO 35
      IF((KDIR.EQ.31).OR.(KDIR.EQ.32)) GOTO 50
   10 CALL PLOT(3.8,5.9,3)
      CALL AROHD(3.8,5.9,3.8,5.3,0.3,0.1,11)
      CALL SYMBOL(4.1,5.3,.100,'SCFM',0.,4)
      CALL NUMBER(4.0,5.5,.100,SCFM,0.,0)
      IF(KDIR.EQ.13) GOTO 20
      CALL PLOT(6.8,5.3,3)
      CALL AROHD(6.8,5.3,6.8,5.9,0.3,0.1,11)
      GOTO 100
   20 CALL PLOT(9.05,5.3,3)
      CALL AROHD(9.05,5.3,9.05,5.9,0.3,0.1,11)
      GOTO 100
   35 CALL PLOT(6.8,5.9,3)
```

```
      CALL ARCHD(6.8,5.9,6.8,5.3,0.3,0.1,11)
      CALL SYMBOL(7.1,5.3,.100,'SCFM',0.,4)
      CALL NUMBER(7.0,5.5,.100,SCFM,0.,0)
      IF(KDIR.EQ.23) GOTO 40
      CALL PLOT(3.8,5.3,3)
      CALL ARCHD(3.8,5.3,3.8,5.9,0.3,0.1,11)
      GOTO 100
   40 CALL PLOT(9.05,5.3,3)
      CALL ARCHD(9.05,5.3,9.05,5.9,0.3,0.1,11)
      GOTO 100
   50 CALL PLOT(9.05,5.9,3)
      CALL ARCHD(9.05,5.9,9.05,5.3,0.3,0.1,11)
      CALL SYMBOL(9.25,5.3,.100,'SCFM',0.,4)
      CALL NUMBER(9.25,5.5,.100,SCFM,0.,0)
      IF(KDIR.EQ.32) GOTO 60
      CALL PLOT(3.8,5.3,3)
      CALL ARCHD(3.8,5.3,3.8,5.9,0.3,0.1,11)
      GOTO 100
   60 CALL PLOT(6.8,5.3,3)
      CALL ARCHD(6.8,5.3,6.8,5.9,0.3,0.1,11)
      GOTO 100
   70 CALL PLOT(3.8,5.9,3)
      CALL ARCHD(3.8,5.9,3.8,5.3,0.3,0.1,11)
      CALL PLOT(6.8,5.3,3)
      CALL ARCHD(6.8,5.3,6.8,5.9,0.3,0.1,11)
      CALL PLOT(9.05,5.3,3)
      CALL ARCHD(9.05,5.3,9.05,5.9,0.3,0.1,11)
      CALL SYMBOL(4.1,5.3,.100,'SCFM',0.,4)
      CALL NUMBER(4.0,5.5,.100,SCFM,0.,0)
  100 RETURN
      END
      SUBROUTINE PLT2DL(DL)
      COMMON N,TL(125),DIA(125),DIP(125),DIN(125),TLP(125),DAY,KDIR
     *,ALPHA(125),DALPHA(125),XL(125),RHC(125),KSEAM(125),ALPHN(125)
     *,RNU(125),TLX(122),DIAX(122),KSMLZ(122),NDAY,DAYMAX,DIAL(122)
      DIMENSION DL(122)
      DO 33 L =1,120
      TLP(L)=TLX(L)/20.0
      DIN(L)=DL(L)/20.0/2.
      DIP(L)=-DIN(L)
   33 CONTINUE
      TLP(121)=0.
      TLP(122)=1.
      DIN(121)=0
      DIN(122)=1.
      DIP(121)=0.
      DIP(122)=1.
      CALL PLOT(3.8,4.,-3)
      CALL DASHLN(TLP,DIN,120,1)
      CALL DASHLN(TLP,DIP,120,1)
      CALL PLOT(-3.8,-4.,-3)
      RETURN
```

```
      END
      SUBROUTINE PLTDLZ(KNH,KD,DLZ)
      COMMON N,TL(125),DIA(125),DIP(125),DIN(125),TLP(125),DAY,KDIR
     *,ALPHA(125),DALPHA(125),XL(125),RHO(125),KSEAM(125),ALPHN(125)
     *,RNU(125),TLX(122),DIAX(122),KSMLZ(122),NDAY,DAYMAX,DIAL(122)
      DIMENSION DLZ(125)
      DO 23 L =1,KNH
      TLP(L)=-DLZ(L)*COS(ALPHA(L))/20.0
      DIN(L)=2.*DLZ(L)*SIN(ALPHA(L))/20.0/2.
      DIP(L)=-DIN(L)
   23 CONTINUE
      DO 33 L =KNH+1,KD
      TLP(L)=TL(L)/20.0
      DIN(L)=DLZ(L)/20.0/2.
      DIP(L)=-DIN(L)
   33 CONTINUE
      TLP(KD+1)=0.
      TLP(KD+2)=1.
      DIN(KD+1)=0
      DIN(KD+2)=1.
      DIP(KD+1)=0.
      DIP(KD+2)=1.
      CALL PLOT(3.8,4.,-3)
      CALL DASHLN(TLP,DIN,KD,1)
      CALL DASHLN(TLP,DIP,KD,1)
      CALL PLOT(-3.8,-4.,-3)
      RETURN
      END
      SUBROUTINE POLFIT(X,Y,NPTS,NTERMS,A,CHISQR)
      DOUBLE PRECISION SUMX,SUMY,XTERM,YTERM,ARRAY,CHISQ
      DIMENSION X(NPTS),Y(NPTS),A(5),SUMX(19),SUMY(10),
     1ARRAY(10,10)
   11 NMAX=2*NTERMS-1
      DO 13 N=1,NMAX
   13 SUMX(N)=0.
      DO 15 J=1,NTERMS
   15 SUMY(J)=0.
      CHISQ=0.
   21 DO 50 I=1,NPTS
      XI=X(I)
      YI=Y(I)
   37 WEIGHT = 1.
      IF(XI.EQ.1.) WEIGHT=0.
   41 XTERM = WEIGHT
      DO 44 N=1,NMAX
      SUMX(N) = SUMX(N) + XTERM
   44 XTERM = XTERM * XI
   45 YTERM = WEIGHT * YI
      DO 48 N=1,NTERMS
      SUMY(N) = SUMY(N) + YTERM
   48 YTERM = YTERM * XI
```

```
   49 CHISQ =CHISQ + WEIGHT*YI**2
   50 CONTINUE
C     CONSTRUCT MATRICIES AND CALCULATE COEFFICIENTS
   51 DO 54 J=1,NTERMS
      DO 54 K=1,NTERMS
      N = J + K - 1
   54 ARRAY(J,K) = SUMX(N)
      DELTA = DETERM (ARRAY, NTERMS)
      IF (DELTA) 61, 57, 61
   57 CHISQR = 0.
      DO 59 J=1, NTERMS
   59 A(J) = 0.
      GO TO 80
   61 DO 70 L=1, NTERMS
   62 DO 65 J=1, NTERMS
      DO 65 K=1, NTERMS
      N = J + K - 1.
   65 ARRAY(J,K) = SUMX(N)
   66 ARRAY(J,L) = SUMY(J)
   70 A(L) = DETERM (ARRAY, NTERMS) / DELTA
C     CALCULATE CHI SQUARE
   71 DO 75 J=1, NTERMS
      CHISQ = CHISQ - 2.*A(J)*SUMY(J)
      DO 75 K=1, NTERMS
      N = J + K - 1
   75 CHISQ = CHISQ + A(J)*A(K)*SUMX(N)
   76 FREE = NPTS - NTERMS
   77 CHISQR = CHISQ / FREE
   80 RETURN
      END
      FUNCTION DETERM (ARRAY,NORDER)
      DOUBLE PRECISION ARRAY,SAVE
      DIMENSION ARRAY(10,10)
C     CALCULATE THE DETERMINANT OF A SQUARE MATRIX
C     NORDER - ORDER OF DETERMINANT (DEGREE OF MATRIX)
C     THIS SUBPROGAM DESTROYS THE INPUT MATRIX ARRAY
C     DIMENSION STATEMENT VALID FOR NORDER UP TO 10
   10 DETERM=1.
   11 DO 50 K=1,NORDER
C     INTERCHANGE COLUMNS IF DIAGONAL ELEMENT IS ZERO
      IF (ARRAY(K,K))  41, 21, 41
   21 DO 23 J=K, NORDER
      IF (ARRAY(K,J)) 31, 23, 31
   23 CONTINUE
      DETERM = 0.
      GO TO 60
   31 DO 34 I=K, NORDER
      SAVE = ARRAY(I,J)
      ARRAY(I,J) = ARRAY(I,K)
   34 ARRAY (I,K) = SAVE
      DETERM = - DETERM
```

```
C       SUBTRACT ROW K FROM LOWER ROWS TO GET DIAGONAL MATRIX
   41 DETERM = DETERM * ARRAY(K,K)
      IF (K- NORDER) 43, 50, 50
   43 K1 = K + 1
      DO 46 I=K1, NORDER
      DO 46 J=K1, NORDER
   46 ARRAY(I,J) = ARRAY(I,J) - ARRAY(I,K) * ARRAY(K,J)/ARRAY(K,K)
   50 CONTINUE
   60 RETURN
      END
      SUBROUTINE SMOOTH(Y,NPTS)
C       SMOOTHS A SET OF DATA POINTS BY AVERAGING ADACENT CHANNELS.
      DIMENSION Y(NPTS)
   11 IMAX=NPTS-1
      YI=Y(1)
   21 DO 24 I=1,IMAX
      YNEW=(YI+2.*Y(I)+Y(I+1))/4.
      YI=Y(I)
   24 Y(I)=YNEW
   25 Y(NPTS)=(YI+3.*Y(NPTS))/4.
      RETURN
      END
      SUBROUTINE HTRL(V,P,WM,PR,POR,X,D,DNC,TB,TW,RE,RA,HCF,HCN,HC,I,KK)
      TFILM=(TB+TW)/2.
      GC=32.2*3600.0
      THCOND=THCDTY(TFILM)
      RHOB=P*144.0*WM/(1545.0*TFILM)
      VISB=7.300E-07*TFILM**0.5/(1.0+189.07/TFILM)*60.0
      RE=RHOB*V*D/VISB
C * * * FORCED CONVECTION IN THE INJECTION REGION * * *
      GZ=RE*PR/POR**.667*D/X
      ANUP=-22.2+6.08*ALOG(GZ)
      IF(GZ.LT.100)ANUP=5.80
      IF(GZ.GT.10000.)ANUP=33.4
      ANUF=ANUP
      HCF=ANUF*THCOND*POR**.667/D
C * * * NATURAL CONVECTION IN THE INJECTION REGION * * *
      RA=((RHOB**2)*GC/TFILM)*ABS(TW-TB)*(DNC**3*PR/POR**.667/VISB**2)
      IF(RA.LE.10**4)GOTO10
      ANUN=0.15*RA**0.25
      GO TO 6
   10 ANUN=1.67*RA**0.167
    6 HCN=ANUN*THCOND*POR**.667/DNC
      HC=(HCF**2+HCN**2)**0.5
      RETURN
      END
      SUBROUTINE QLINKE(FLRMBT,P,BMW,PR,YVM,YMOIST,X1,TB,TW,TVOL,
     1  SMTK,KD,VMC,RHOC,I,DELTAT,CPGAS,DNC,GMXS)
C THIS SUBR. CALC. VM DEVOL. FROM END OF CAVITY, DOWNSTREAM IN LINK.
      DIMENSION XLX(122)
      COMMON N,TL(125),DIA(125),DIP(125),DIN(125),TLP(125),DAY,KDIR
```

```
     *,ALPHA(125),DALPHA(125),XL(125),RHC(125),KSEAM(125),ALPHN(125)
     *,RNU(125),TLX(122),DIAX(122),KSMLZ(122),NDAY,DAYMAX,DIAL(122)
      PI=3.1416
C     X1=AINT(X1)
C A MAX KK OF 113 TAKES FLOW TO P/I-3 PROD WELL
      DO 10 KK=1,113
      IF(TLX(KK).LT.(X1+.50))GOTO 10
      K1=KK
C     IF(K1.GE.113)GOTO 130
      GOTO 20
   10 CONTINUE
   20 IF(I.NE.2)GOTO 50
      DO 40 KK=K1,113
      IF(DIAX(KK)-1.128*SMTK)30,35,35
   30 KSMLZ(KK)=1
      GOTO 40
   35 KSMLZ(KK)=2
   40 CONTINUE
   50 CONTINUE
      DO 60 KK=K1,113
   60 XLX(KK)=1.00
      IF(ABS(DAY+0.02-NDAY).GE.1.0) WRITE(6,51)
      IF(DAY.GE.DAYMAX-.01)WRITE(6,51)
C     WRITE(6,51)
   51 FORMAT(/,3X,'I KK  DAY          TL(K) DX(K)  FLMBT FLMVM        VM
     *C          RE NO     RA ND   HCNAT HCTOT FLRBT  GVMW  S TBIN  TWALL
     * TBULK       ',/)

C DO THE KK LOOP OVER EACH SECTION
      DO 700 KK=K1,113
      SL=TLX(KK)-X1
      IF(KSMLZ(KK).EQ.2)GOTO411
      IF(DIAX(KK)-1.128*SMTK)405,401,401
  405 WFRCT=1.0
      AW=PI*DIAX(KK)*XLX(KK)
      AS=PI*DIAX(KK)**2/4.
      DHYDR=DIAX(KK)
      GOTO 909
  401 KSMLZ(KK)=2
      DIAX(KK)=PI*DIAX(KK)**2/4./SMTK
  411 AS=SMTK*DIAX(KK)
      AW=2.*(SMTK+DIAX(KK))*XLX(KK)
      WFRCT=2*SMTK*XLX(KK)/AW
      DHYDR=2.*DIAX(KK)*SMTK/(DIAX(KK)+SMTK)
  909 RHOB=RHO(P,BMW,TB)
      VELB=FLRMBT/RHOB/AS
      TFILM=(TW+TB)/2.
      CALL HTRL(VELB,P,BMW,PR,YVM,SL,DHYDR,DNC,TB,TW,RE,RA,HCF,
     1  HCN,HC,I,KK)
      QRW=HC*AW*WFRCT*(TW-TB)
      QBW=HC*AW*(1.-WFRCT)*(TW-TB)
```

```
      FLRMVM=-YVM*GRW/(YMDIST*800.+80.+0.30*(TB-TW))
      FLRMBT=FLRMBT+FLRMVM*(1.+YMDIST/YVM)
      VMC=VMC+FLRMVM*DELTAT*60./2000.
      TBIN=TB
      TB=TBIN+(GRW+GBW)/FLRMBT/CPGAS
      GVMW=FLRMVM/AW/WFRCT
      DRHC=FLRMVM*DELTAT*60./RHOC/AW/WFRCT/YVM
      DIAX(KK)=DIAX(KK)+2.*DRHC
      IF(ABS(DAY+0.02-NDAY).GE.1.0) GOTO 84
      IF(DAY.GE.DAYMAX-.01)GOTO 84
      GO TO 699
   84 WRITE(6,90)I,KK,DAY,TLX(KK),DIAX(KK),FLRMBT,FLRMVM,VMC,RE,
     *RA,HCN,HC,FLRMBT,GVMW,KSMLZ(KK),TBIN,TW,TB
   90 FORMAT(1X,I3,1X,I3,F7.2,4X,1X,F6.2,1X,F5.2,1X,F6.2,F6.2,6X,
     *F6.0,6X,2E10.2,F5.2,F6.2,F6.1,F7.4,I2,1X,F5.0,F6.0,F6.0,1X,6X)
  699 IF(TB.LE.TVOL)GOTO 130
  700 CONTINUE
  130 CONTINUE
      RETURN
      END
```

5.9 3-D Plot Computer Program: UCG3D3

```
      PROGRAM UCG3D3(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE2)
      DIMENSION IBUF(512),Y(125,8),Z(125,8)
     *,TL(125),DIA(125),TLP(125)
     *,KSEAM(125),TB1(125),TW1(125)

      CALL PLOTS(IBUF,512,2,50)
      READ(6,101)NPLOTS,TITLE
      READ(5,101)NPLOTS,KNH
101   FORMAT(2I5)
      WRITE(6,101)NPLOTS,KNH
NPLOTS IS NO. OF PLOTS TO BE MADE & SETS OF DATA
      DO 200 JPLOT=1,NPLOTS
      READ(5,100)KD
      WRITE(6,100)KD
100   FORMAT(I5)
READ INPUT FROM CLE OR FG OUTPUT FILE AS MODIFIED
      READ(5,5)DAY,DAYJ1,DURA,SCFM,RCO1,SMTK,P,DELTAT,RHOC,POR,N
     *,NTHICK,RVMO2,RCHO2,FCHR,GMR,GMXS,GMRCH,GCHR,FOXCH,FWGCH,KDIR,RCO2
     *,COCO2
    5 FORMAT(T10,9X,F10.2,T30,9X,F10.3,T50,9X,
     * F10.3,/,T10,9X,F10.2,T30,9X,F10.2,T50,9X,
     *F10.2,/,T10,9X,F10.2,T30,9X,F10.2,T50,10X,
     *F10.2,/,T10,9X,F10.2,T30,9X,I8,T50,14X,I4
     *,/,T10,10X,F10.3,T30,12X,F7.3,T50,10X,F10.3
     *,/,T10,12X,F7.3,T30,10X,F10.3,T50,15X,
     * F8.3,/,T10,11X,F9.3,T30,10X,F10.3,T50,10X,
     * F10.3,/,T10,10X,I10,T30,9X,F10.3,T50,10X,
     *  F10.3,)
      WRITE(6,105)DAY,DAYJ1,DURA,SCFM,RCO1,SMTK,P,DELTAT,RHOC,POR,N
     *,NTHICK,RVMO2,RCHO2,FCHR,GMR,GMXS,GMRCH,GCHR,FOXCH,FWGCH,KDIR,RCO2
     *,COCO2
105   FORMAT(/,T10,'DAY    =',F10.2,T30,'DAYJ1 =',F10.3,T50,'DURATN=',
     * F10.3,/,T10,'SCFM   =',F10.2,T30,'RCO1   =',F10.2,T50,'SM THK=',
     *F10.2,/,T10,'P      =',F10.2,T30,'DELTAT=',F10.2,T50,'RHOC   =',
     *F10.2,/,T10,'PORSTY=',F10.2,T30,'N INT =',I8,T50,'OPT TK IF 1:',I4
     *,/,T10,'R(VM/O)=',F10.3,T30,'R(CH,R/O)=',F7.3,T50,'F(CH,R)=',F10.3
     *,/,T10,'GAM REACT=',F7.3,T30,'GAM EXS=',F10.3,T50,'GAM REACT,CH=',
     * F8.3,/,T10,'GAM CH,R=',F9.3,T30,'FOX,CH =',F10.3,T50,'FWG,CH =',
     * F10.3,/,T10,'KDIR    =',I10,T30,'RCO2   =',F10.3,T50,'CO/CO2 =',
     *  F10.3,/)
      DO 210 K=1,KD
      READ(5,90)I,L,FN,TL(K),DIA(K),FLRMBL,FLRMDY,FLRMOL,CHC,WOX,
     *RE,RA,HMN,HM,FLRMBT,GOXW,KSEAM(K),KCHR,CFM,TW1(K),TB1(K)    ,DCIRC
 90   FORMAT(1X,I3,I3,1X,F7.4,F6.2,1X,F5.2,1X,F6.2,2F6.2,F6.0,
     *F6.3,2E10.3,F5.2,F6.2,F6.1,F7.4,I2,1X,I3,1X,F5.0,2F6.0,1X,F6.2)
      WRITE(6,90)I,L,FN,TL(K),DIA(K),FLRMBL,FLRMDY,FLRMOL,CHC,WOX,
     *RE,RA,HMN,HM,FLRMBT,GOXW,KSEAM(K),KCHR,CFM,TW1(K),TB1(K)    ,DCIRC
```

```
  210 CONTINUE
      DO 250 K=1,KD
      RAD=DIA(K)/2./20.
      HHT=SMTK/2./20.
      TLP(K)=TL(K)/20.
      YZERO=4.00
      ZZERO=2.00
      TLY=YZERO+TLP(K)*0.707
      TLZ=ZZERO+TLP(K)*0.707
      IF(KSEAM(K).EQ.2)GOTO350
      RCOS=RAD*0.707
      Y(K,1)=TLY+RCOS
      Y(K,3)=TLY+RCOS
      Y(K,5)=TLY-RCOS
      Y(K,7)=TLY-RCOS
      Y(K,4)=TLY+0.0
      Y(K,8)=TLY+0.0
      Y(K,2)=TLY+RAD
      Y(K,6)=TLY-RAD
      Z(K,1)=TLZ-RCOS
      Z(K,7)=TLZ-RCOS
      Z(K,3)=TLZ+RCOS
      Z(K,5)=TLZ+RCOS
      Z(K,2)=TLZ+0.0
      Z(K,6)=TLZ+0.0
      Z(K,4)=TLZ+RAD
      Z(K,8)=TLZ-RAD
      GOTO 250
  350 Y(K,1)=TLY+RAD
      Y(K,2)=TLY+RAD
      Y(K,3)=TLY+RAD
      Y(K,4)=TLY+0.0
      Y(K,8)=TLY+0.0
      Y(K,5)=TLY-RAD
      Y(K,6)=TLY-RAD
      Y(K,7)=TLY-RAD
      Z(K,1)=TLZ-HHT
      Z(K,7)=TLZ-HHT
      Z(K,8)=TLZ-HHT
      Z(K,2)=TLZ+0.0
      Z(K,6)=TLZ+0.0
      Z(K,3)=TLZ+HHT
      Z(K,4)=TLZ+HHT
      Z(K,5)=TLZ+HHT
C     CALL THREED(-20,-40,-4,120,40,4,TL,WY,KROWS,16,KD,Z,2,7,2,315,
C    *  30,0.5)
  250 CONTINUE
      IF(JPLOT.EQ.1)GOTO850
      IF(JPLOT.EQ.4)GOTO800
      IF(JPLOT.EQ.7)GOTO800
      IF(JPLOT.EQ.10)GOTO800
```

```
      IF(JPLOT.EQ.13)GOTO800
      GOTO 800
C PLOT SCALE FIGURE
  800 CALL PLOT(10.00,0.,-3)
  850 CALL PLOT(4.00,5.00,3)
      CALL PLOT(4.00,6.00,2)
      CALL PLOT(3.95,6.00,2)
      CALL PLOT(4.71,5.75,3)
      CALL PLOT(4.71,5.70,2)
      CALL PLOT(4.00,5.00,2)
      CALL PLOT(5.00,5.00,2)
      CALL PLOT(5.00,5.05,2)
      CALL SYMBOL(4.80,5.10,0.1,'20 FT',0.,5)
      CALL SYMBOL(4.61,5.80,0.1,'20 FT',0.,5)
      CALL SYMBOL(3.70,6.05,0.1,'20 FT',0.,5)
      CALL NUMBER(3.80,4.95,0.1,0.,0.,-1)
      CALL SYMBOL(4.20,6.30,0.1,'SCALE',0.,5)
C XMIN MUST BE NEGATIVE IF CAVITY STARTS AT NEGATIVE X
  900 XMIN=FN
      YS=4.00+XMIN/20.*0.707
      ZS=2.00+XMIN/20.*0.707
  400 DO 450 J=1,8,2
      CALL PLOT(YS,ZS,+3)
      DO 450 K=1,KD
      CALL PLOT(Y(K,J),Z(K,J),+2)
  450 CONTINUE
C     DO 500 J=6,8
C     CALL PLOT(YS,ZS,+3)
C     DO 500 K=1,KNH
C     CALL PLOT(Y(K,J),Z(K,J),+2)
C 500 CONTINUE
      DO 700 KL=1,8
      KK=KL
      GOTO(510,520,530,540,550,560,570,580),KK
  510 K=8
      IF(KSEAM(K)-1)590,590,600
  520 K=16
      IF(KSEAM(K)-1)590,590,600
  530 K=18
      IF(K.GE.KD-2)GOTO 700
      IF(KSEAM(K)-1)590,590,600
  540 K=24
      IF(K.GE.KD-2)GOTO 700
      IF(KSEAM(K)-1)590,590,600
  550 K=28
      IF(K.GE.KD-2)GOTO 700
      IF(KSEAM(K)-1)590,590,600
  560 K=32
      IF(K.GE.KD-2)GOTO 700
      IF(KSEAM(K)-1)590,590,600
  570 K=37
      IF(K.GE.KD-2)GOTO 700
```

```
      IF(KSEAM(K)-1)590,590,600
  580 K=KD
      IF(KSEAM(K)-1)590,590,600
  590 RAD=DIA(K)/20.0/2.0
      CALL CIRCLE(Y(K,8),Z(K,8),-90.,270.,RAD,RAD,0.0)
      GOTO 700
  600 CALL PLOT(Y(K,8),Z(K,8),+3)
      DO 650 J=1,8
      CALL PLOT(Y(K,J),Z(K,J),+2)
  650 CONTINUE
  700 CONTINUE
C     CALL AXIS(4.00,2.00,' ',+0,2.0,90.0,0.,20.)
C     CALL AXIS(6.37,4.37,' ',+0,2.0,90.0,0.,20.)
C     CALL AXIS(3.29,1.29,' ',+0,5.0,45.0,-20.,20.)
C     CALL AXIS(3.00,1.00,' ',-0,2.0,0.0,-20.,20.)
      CALL SYMBOL(4.10,4.00,0.1,'P/I-1',0.0,5)
      CALL SYMBOL(6.47,6.37,0.1,'P/I-2',0.0,5)
      CALL SYMBOL(3.50,1.30,0.1,'DAY =',0.0,5)
      CALL NUMBER(4.10,1.30,0.1,DAY,0.0,0)
C PLOT FIRST WELL
      CALL PLOT(4.00,1.95,3)
      CALL PLOT(4.00,2.05,2)
      CALL PLOT(4.00,2.10,3)
      CALL PLOT(4.00,4.00,2)
      CALL PLOT(3.95,4.00,2)
      CALL PLOT(3.95,3.00,3)
      CALL PLOT(4.00,3.00,2)
C PLOT SECOND WELL
      CALL PLOT(6.37,4.32,3)
      CALL PLOT(6.37,4.42,2)
      CALL PLOT(6.37,4.47,3)
      CALL PLOT(6.37,6.37,2)
      CALL PLOT(6.32,6.37,2)
      CALL PLOT(6.32,5.32,3)
      CALL PLOT(6.37,5.32,2)
C PLOT CAVITY CENTERLINE
      CALL PLOT(3.29,1.29,3)
      CALL PLOT(3.90,1.90,2)
      CALL PLOT(3.95,1.95,3)
      CALL PLOT(4.05,2.05,2)
      CALL PLOT(4.10,2.10,3)
      CALL PLOT(6.27,4.27,2)
      CALL PLOT(6.32,4.32,3)
      CALL PLOT(6.42,4.42,2)
      CALL PLOT(6.47,4.47,3)
      CALL PLOT(6.90,4.90,2)
      CALL PLOT(2.37,0.,-3)
  200 CONTINUE
      CALL PLOT(0.0,0.0,999)
      STOP
      END
```

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